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NATURAL REPRODUCTION OF QUINNAT SALMON, BROWN AND RAINBOW TROUT IN CERTAIN NEW ZEALAND WATERS.

BY

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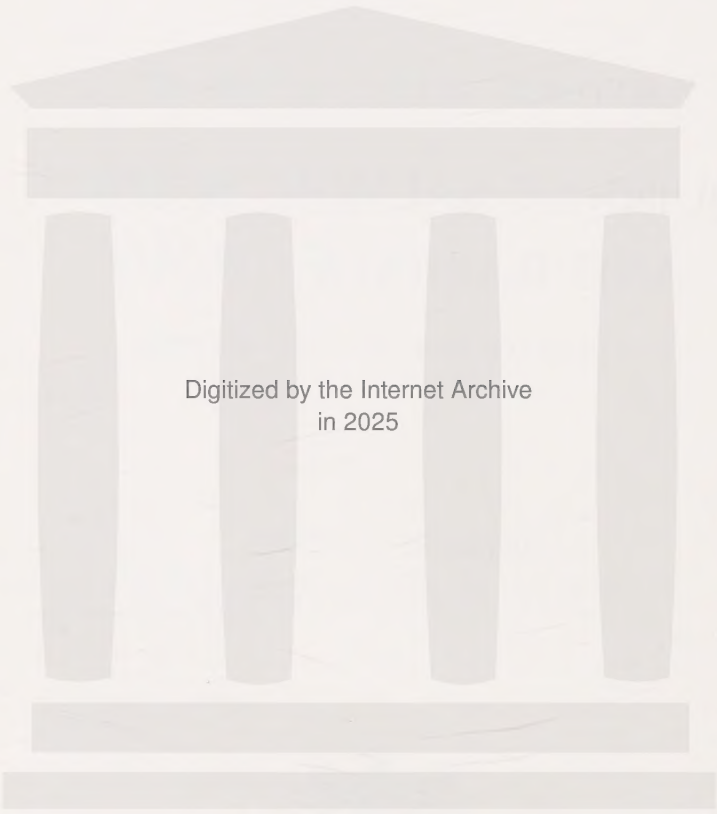
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PREFACE.

THERE is special need of a foreword to this report since it is due to its author, Mr. Hobbs, and perhaps to other workers in the same field, that attention should be called to the fact that the observations upon which it is based were begun in the winter of 1932, continued during 1933, and a draft report was submitted in typescript to the Fresh-water Research Committee of the New Zealand Acclimatization Societies Association early in 1934, which, except for minor emendations, was substantially the same as this report now belatedly published by the Marine Department as Fisheries Bulletin No. 6. It should also be mentioned that, although the elucidation of the spawning-conditions was recognized as an essential phase of the investigation of the Salmonidæ in New Zealand which had been placed in the hands of the Fresh-water Research Committee, the observations on which this report is made were begun at the author's own initiative as occupation for a winter vacation from city employment. Mr. Hobbs was then acting as Honorary Research Secretary to the Committee. It was several months after the draft of this report had been in the hands of the Committee that he was appointed to a salaried post on the staff—a recognition of the desirability of continuing and extending this line of investigation.

Apart from its value as a contribution to a phase of salmonid biology of considerable practical importance in connection with the management of our inland fisheries, this work has a special interest as an attack upon a set of problems that does not appear to have been undertaken in the same way by any previous investigators of the spawning phenomena of salmon and trout. The methods and the precautions devised for the collection of material and other evidence in the streams and the painstaking analysis of data for the purpose of checking their validity are features of Mr. Hobbs's work that should place it among the important contributions to this branch of fishery investigation.

The observations have subsequently been extended to some of the principal trout streams in the southern part of the South Island and in the Auckland Province in the North Island, and are still going on. This paper may therefore be regarded as the first of a series designed to throw a much-needed light on the natural propagation of the Salmonidæ in New Zealand.

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CONTENTS.

	PAGE
SECTION I.—INTRODUCTION	7
SECTION II.—THE SPAWNING OF QUINNAT SALMON—	
A. Spawning-areas in the Waimakariri River System	13
B. Salmon in the Broken River System	14
SECTION III.—THE SPAWNING OF BROWN TROUT—	
A. Brown Trout in Slovens Creek	38
B. Brown Trout in Inchbonnie Streams	50
C. Brown Trout in the Selwyn River	60
D. Sundry Redds of Brown Trout	65
SECTION IV.—RAINBOW TROUT IN WINDING CREEK	66
SECTION V.—LIFE IN THE REDDS	67
SECTION VI.—THE CAUSES OF LOSSES—	
A. Losses outside the Redds	69
B. Losses in the Redds	73
C. Flood Losses	81
D. Superimposition of Redds	88
E. Other Possibilities of Loss	90
SECTION VII.—PRACTICAL CONSIDERATIONS	92
SECTION VIII.—CONCLUSIONS	93
SUMMARY	94
ACKNOWLEDGMENTS	96
REFERENCES	97
APPENDICES	98

Natural Reproduction of Quinnat Salmon, Brown and Rainbow Trout in certain New Zealand Waters.

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SECTION I.—INTRODUCTION.

The following paper is an account of a preliminary investigation of the efficiency of natural reproduction of brown trout (*Salmo trutta*), quinnat salmon (*Onchorhynchus tschawytscha*), and rainbow trout (*S. irideus*) in certain New Zealand waters. No earlier attempts have been recorded at the quantitative determination of the extent of losses in the natural spawning-redds of these species in New Zealand.

Doubts as to both the extent and the causes of losses in the redds of Salmonidæ are not confined to New Zealand. The similarity of the methods of incubation of eggs of different species suggests that a review of any inquiries made elsewhere as to losses in redds of Salmonidæ, whether or not of species established in this country, should be worth considering.

Expressions of opinion as to what may be expected to happen to ova deposited in natural redds are not lacking in fisheries literature. Such expressions of opinion have, in their presentation, seldom been accompanied by supporting evidence. Where quantitative expression of losses occurring in redds has been attempted, indefinite terms such as "enormous" have often been used. The basis on which such estimates have been made has not been given. Much that has been written may be dismissed as sweeping assertion unsupported by any weight of satisfactory data. The following review of precedents is not exhaustive. It fairly illustrates the extent and value of earlier investigational work.

Precedents.

Francis Day(5), writing in 1887 of the spawning of Salmonidæ in England, stated: "It must be very apparent that numerous causes may be in existence, either to prevent fertilization or, should such have taken place, to subsequently destroy the ova. Among these deleterious agencies are the

character or polluted state of the water, or that when the eggs are being deposited in running streams they may escape the influence of the milt, or even be carried away by the current, or overwhelmed by mud. Or the water may subside to that extent that they are left uncovered, and perish by drought or frost or else consumed by fish in the vicinity, who will even root them up for this purpose. When safely deposited in redds they still have enemies to contend with—floods may sweep them away, or, should such a state of the rivers continue for any length of time, the fish may not be able to avail themselves of their usual breeding-grounds, they being too deep in the water. This may compel them to drop their eggs in the swollen stream, when they would become smothered by mud or otherwise lost, or the fish might push up higher into smaller watercourses, which would render the chances considerable of the eggs being left uncovered upon a subsidence taking place. Irrespective of the seasons, the eggs have numerous enemies, as fish, the larvæ of the dragon-flies, the may and stone flies, and the caddis-flies, some birds . . . , while the house-rat, mice, and also the vole or water-rat join in their destruction. As the mortality among the eggs left to hatch in rivers and streams is so enormous, while it is impossible to destroy their enemies which exist there, it has become obvious that great gain might accrue were the ova to be collected and artificially incubated."

The listing, by Day, of supposed or known causes of losses does not justify the use of the quantitative expression " enormous " in regard to losses. It is not proposed to discuss the possibilities listed by Day. A statement is made that certain animals prey on eggs. Studies of the animal life in Yorkshire streams, made by Percival and Whitehead(17), in types of bottom material, which from the descriptions appear suitable for spawning of brown trout, showed that only 3 per cent. of the beasts present were carnivorous. The other 97 per cent., on some of which these carnivores feed, themselves feed on vegetable matter. This vegetable matter is found on the surface of the stream-beds. As will be shown later, trout-ova are incubated at a depth of about 8 in. below the surface of the beds of streams, in a region remarkably free from the aquatic animals—larvæ of dragon-flies, may-flies, stone-flies, and caddis-flies—which Day considers to be inimical.

Armistead(1), writing in 1898, said that, " The host of creeping things found at the bottom of our streams almost without exception prey extensively upon trout-ova . . . There are creatures innumerable all instinctively attracted to the place where the eggs are deposited—caddis-worms, creepers, shrimps, beetles, frogs, mice, rats, ducks and other fowl, eels, trout, grayling, salmon, sea trout, and nearly every other fish found in the streams. Nearly everything ranks as an enemy to trout-ova." Again he says, " It has often been stated by scientists and others that only about one trout or salmon egg in a thousand deposited in our streams produces a mature fish. This is probably not far from the mark. Anyhow, we are quite sure of one thing, and that is that the rule applies to 99 per cent. of the ova deposited naturally in our streams ; 75 per cent. of this loss probably occurs before the eggs are hatched and during the hatching-period." While it is probable that some of the supposed enemies of trout-ova which Armistead lists might eat ova which fail to lodge in the redds, it is difficult to understand why some of the creatures should be instinctively attracted to the places where ova are, or how they would get at the ova even if attracted. No evidence is produced by Armistead to justify an attempt at quantitative expression of losses.

In 1902 Rutter(19) endeavoured to ascertain what losses occurred in redds of quinnat salmon. He showed that of one sample of ova 76 per cent., and of another 82 per cent., had been fertilized, when fish spawned in a specially prepared race. When, in two experiments, eggs and milt were artificially expressed from fish held under water, over natural redds, 35 per cent. and 50 per cent. respectively of the ova recovered were fertilized. Rutter noted that subsequently there was a high but indefinite mortality attributable, he considered, to ova being covered with gravel. He considered that the greatest loss of quinnat-ova was due to the depredations of spawning fishes. His estimates of percentage losses are as follows : Not spawned, per cent. ; unfertilized, 15 per cent. ; killed before hatching, 70 per cent. ; alevins killed, 13 per cent. : total loss, 99 per cent. The material from which the non-fertilization loss was ascertained was very meagre, and Rutter states that no definite data were available for the ascertainment of the third and fourth loss figures.

Babcock(2) in 1910, as the result of the experimental planting of ova of Pacific Coast salmon (*Onchorhynchus* sp.), found that for satisfactory incubation burial at a depth of at least 5 in. or 6 in. in sand and gravel was necessary. He states that "eggs not covered by several inches of sand and gravel are either consumed by active aquatic enemies or destroyed by vegetable moulds, commonly termed 'fungus'." It will be noted that Rutter attributed losses to the fact that ova were covered with gravel ; Babcock found that ova had to be so covered to live.

Moseley(15, 1926) states that "It is not generally realized how wasteful is Nature in the matter of the eggs of the trout. Left to themselves, the mortality is immense. An hour or so after fertilization the trout-eggs become extremely susceptible to the least shock or disturbance and remain in this state until a week or so before the alevins emerge—*i.e.*, until they reach the stage in which they are described as 'eyed' ova. Consequently it happens that where spawning-grounds are limited in area trout after trout come up to spawn on the same ground, ruthlessly tearing up the eggs of their predecessors ; it may be safely assumed that all the first eggs laid down in the redds are destroyed and that it is only the progeny of the last comers that have a chance to grow up to maturity." Moseley presents no data on which the soundness or otherwise of his assumption can be judged, nor does he show adequate grounds for describing the mortality among eggs as immense.

Calderwood(4, 1930) states that in examining natural redds (presumably of *S. trutta* or *S. salar*) he has never found many eggs. But of those found "none have been dead or crushed and practically none unfertilized."

Hazzard(11) examined twenty-one redds of eastern brook trout, *Salvelinus fontinalis* Mitchell. The twenty-one samples of ova obtained were taken in the eyed stage and averaged 201 specimens each. The number containing embryos was stated to vary from 26 per cent. to 98·5 per cent. per sample, with an average of 79·8 per cent. The aim of the investigation was stated to be the determination of the percentage of fertilization. Unfortunately, no mention is made of any means of determining fertility, other than by the presence of embryos in samples comprising eyed ova. The present writer has found it impossible to distinguish unfertilized ova, which had undergone exosmosis, from fertilized ova which died a few days after fertilization, when such ova have not been recovered until survivors of the same lot have reached the eyed stage. It seems possible that the loss of 20·2 per cent. does not consist of non-fertilized eggs alone. It may also include any

fertilized eggs which died before the embryos in them had attained to a sufficient size to be still distinguishable by the time live eggs had become eyed.

The only thorough inquiry into losses in natural spawning-redds of any species of Salmonidæ of which the writer has found records is that at present being conducted by Foerster(6) on sockeye salmon (*O. nerka*). This particular investigation aims, *inter alia*, at the determination of the percentage of fertilization, the percentage of eggs that hatch, and the percentage of free-swimming fry produced. Reports so far issued show that the extent of the total loss up to the time of downstream migration has been determined but that this loss has not been apportioned among earlier growth stages or among causes of loss.

Briefly, then, it seems that whereas certain factors are reputed to cause losses in natural redds, there is no reasonably accurate knowledge in the case of any species of Salmonidæ, in any particular environment, as to the extent of the loss which occurs or as to what portions of such loss may be attributed to any specific causes. In making, in 1932, 1933, and 1934, the observations here recorded, no pre-arranged programme was followed. The scheme of attacking the two main problems—of quantitative determinations of losses and of the causes of such losses—was developed as the work progressed.

Methods.

Rutter (*loc. cit.*) advocated the method subsequently employed by Foerster —this is, the permitting of the spawning of fish of known productivity in a controlled area and the trapping of the resultant fry as downstream migrants. Such a method alone throws no light on the causes of losses nor does it enable losses occurring in the redds to be distinguished from losses taking place subsequently, but before migration. The artificial planting of known numbers of fertilized ova under control conditions is also objectionable in that it sheds no light on the extent of fertilization in Nature. Further, there is no certainty that natural conditions could be simulated with sufficient exactitude, or that screens placed round experimental areas would not modify flood action.

The procedure adopted was to study, in the field, the spawning-habit of fish and the conditions affecting the well-being of their progeny in the redds. Redds were kept under observation in selected areas for the purpose of ascertaining whether eggs, once safely lodged in the redds, or alevins when hatched from such eggs, were ever fortuitously removed from the redds. The times required for ova and alevins, dying in redds, to decompose to an irrecoverable stage were determined. Samples of material at successive stages of development were recovered from redds. The extent of the loss up to each stage was determined. Where necessary allowance was made for dead specimens so decomposed as to be no longer recoverable. Factors in environments where losses were very heavy were noted for comparison with factors in environments where losses were very light. The possibilities of losses being heavier in some cases than in others through inherent weakness of ova were examined.

Locale of Observations.

Field observations were carried out in a belt of country, in the middle portion of the South Island of New Zealand, extending from the Pacific coast in Canterbury to within eighteen miles of the Tasman coast in Westland

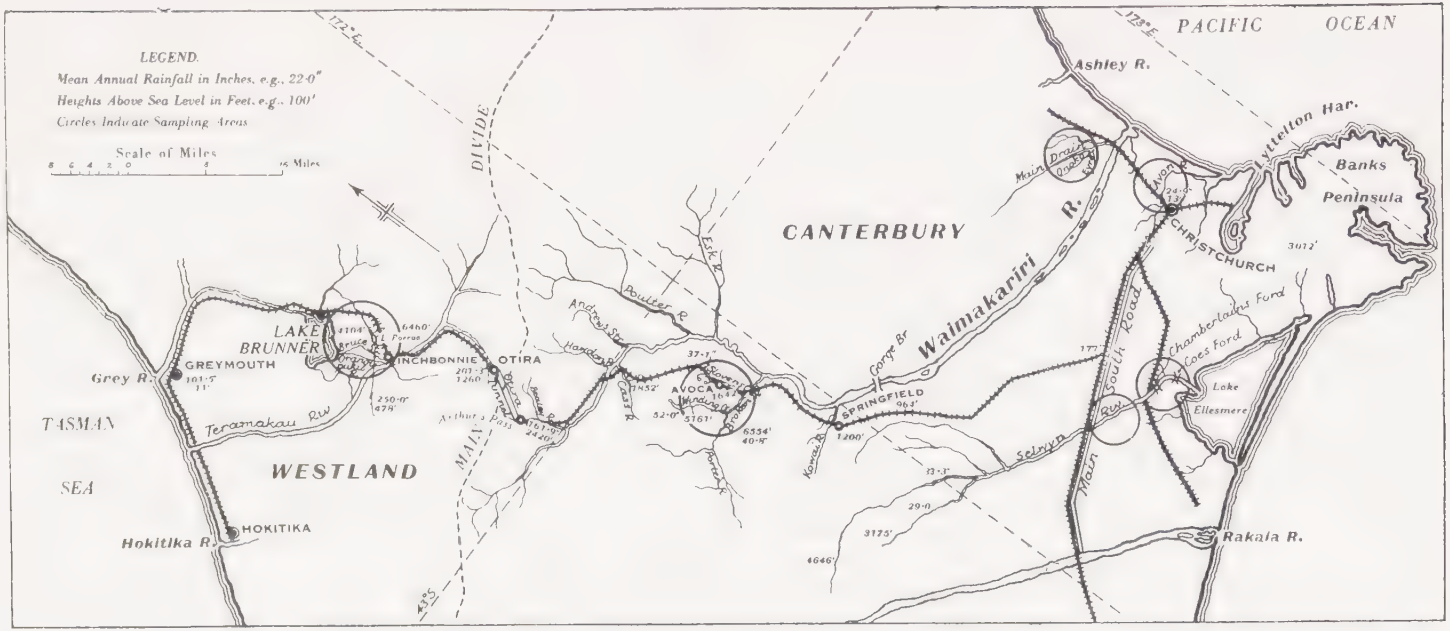

FIG. 1.—Portion of South Island of New Zealand showing areas from which material was collected.

In the coastal area of Canterbury observations were made on spawning-redds of brown trout in the Selwyn River and in the Avon River and Main Drain. In the vicinity of the flag station of Avoca, on the Midland Railway Line, at a point 1,642 ft. above sea-level, in the eastern foothills of the Southern Alps, observations were made in a portion of the Waimakariri River system. In this area conditions in redds of quinnat salmon were studied in Broken River and in Winding and Slovens Creeks, redds of brown trout in Winding and Slovens Creeks and redds of rainbow trout in Winding Creek. At Inchbonnie, in Westland, in the western foothills of the Southern Alps, observations, limited to the redds of brown trout, were made in streams comprising the left-hand branch of the Orangipuku River and in two tributaries of Lake Poerua. These areas are shown in Fig. 1.

Terminology.

Redd.—The total area excavated by a fish in any one portion of a stream-bed and in which ova have been deposited. Where one fish, at the same spawning, excavates several such areas, and they are not contiguous, they are separate redds.

Trial redd.—An area partially excavated by a fish and then abandoned without deposition of ova.

Egg stratum.—The lowest plane in the vertical section of a redd; that which immediately overlies the undisturbed bottom of the redd. Ova are found almost exclusively on this plane in redds.

Egg pocket.—The very small portion of the egg-stratum in which eggs are found. There may be more than one pocket in a redd.

Clean or dirty redds.—The words "clean" and "dirty," used in reference to redds, denote a relative absence or abundance, respectively, in egg-pockets, of such very fine material as causes turbidity on disturbance of the pockets. The discoloration of water caused by the disturbance of sand and coarser materials is negligible. Redds containing egg-pockets comprising such materials alone would be described as very clean. The composition of material above the egg-stratum is not taken into account in this classification of redds.

Infertile ova.—Eggs in which segmentation has not taken place, whether lack of segmentation is due to lack of contact of sperms with blastodiscs or to inherent defects of ova. The terms "fertile" and "infertile" are not used as analogous to "live" and "dead" respectively. Thus there may be dead fertile ova, where death has followed segmentation.

Chorion.—The tough outer membrane, or "shell," of the egg.

Exosmosis.—The loss of osmotic stability: the loss of soluble salts from the yolk of the egg, with the result that the yolk coagulates and the egg becomes opaque. This process has been fully described by Gray(8).

Incubation.—The duration of life of embryos in the eggs from fertilization until hatching.

Alevinage.—The duration of life of alevins (larvæ) from hatching until all yolk, whether or not visible through the ventral surface, is absorbed.

"Green" eggs.—Ova freshly taken from a fish; ova before their specific gravity has dropped and weight increased, as happens following immersion in water.

SECTION II. THE SPAWNING OF QUINNAT SALMON.

A. SPAWNING-AREAS IN THE WAIMAKARIRI RIVER SYSTEM.

Intensive observations were confined to a portion of the Broken River and two of its tributaries, Winding and Slovens Creeks. The Broken River is itself a tributary of the Waimakariri River, to which, it is generally conceded, quinnat have spread naturally from the Waitaki, a more southerly river in which they were first established. All examinations of redds were made in 1933, although a few general observations were made during a preliminary survey in 1932.

No general survey of the spawning-areas in the Waimakariri River system has been attempted. On observations made and information received—particularly that contained in the letters of Messrs. A. D. Dickie, J. H. Kidd, R. A. Blackley, and J. G. Thompson (*vide* Appendix A)—the following inconclusive description is based: The extent of spawning, if any, in the first thirty-six miles of water across the Canterbury Plains, between the mouth and the Gorge Bridge, is not known. No significant tributaries enter the river in this area, excepting the several small streams which together form the Cam, and enter in the tidal area. In one of these the Main Drain—mature salmon have, very rarely, been reported seen. The river temporarily narrows at the Gorge Bridge. The bed above it is again fairly wide for a few miles. Between the Gorge Bridge and Springfield, a distance of about five miles, fish are reported to spawn in very large numbers. Near Staircase and the entrance of the Broken River, some fifty-two miles from the sea and eleven miles above Springfield, in the less-confined portion of the Waimakariri Gorge, a more limited amount of spawning occurs. In the nine miles of gorge between the entrances of the Broken and Esk Rivers, if redds are made at all, it is improbable that they are numerically significant. Above the gorge the river again flows through a fairly wide flood-bed. Throughout the twenty-two miles that this type of bed continues, as far up as the junction of the Bealey and the Waimakariri—a point marking the upward limit of the run—considerable spawning occurs. There is no obstruction to impede an upward movement of fish past the junction of the Bealey and Waimakariri, yet a steady reduction in spawning activity between the entrance of the Cass River and this point is observable.

Fish are known to spawn in the following tributaries of the Waimakariri: Hacket's Creek, a short swamp creek entering from the southern side near Springfield; Broken River, a turbulent snow-fed stream and its tributaries, the Porter River and Winding and Slovens Creeks; the Esk River, snow-fed, entering from the north above the gorge, and its tributary the Thompson; the Poulter River, another snow-fed stream, entering from the north above the Esk; the Cass River, snow-fed, entering from the south, and a small creek which drains from Lake Sarah into it. An ample description of the Waimakariri and its principal tributaries is given by Speight(20).

B. QUINNAT IN THE BROKEN RIVER SYSTEM.

Nature of the Streams.

Broken River.

Broken River, a snow-fed stream, rises in the Craigieburn Range. It flows thence in an easterly direction along the northern side of the Torlesse Range. It enters the lower portion of the Waimakariri Gorge about a mile above Staircase Railway Station. Speight (*loc. cit.*) gives its drainage area as 154 square miles, of which 18 square miles are in native bush. The Porter River and other smaller tributaries join Broken River in a limestone area within a few miles of its source, and the combined streams are thereafter confined to a fairly open gorge for six miles until Winding Creek enters from the north. The walls of this gorge are in parts scrub-covered and in others consist of crumbling greywacke. Narrow vegetation-covered flats and bare shingle banks occur at intervals along this part of the course. The nature of the stream-bed changes below Winding Creek. The banks are generally less precipitous and the bed is wider, with a very limited amount of vegetation on low-lying marginal flats. Thereafter the river enters a short gorge for half a mile, to open out again at Scrubby Flat into a shingle flood-bed varying in width from 100 yards to 400 yards. A very limited amount of vegetation is found in this flood-bed. Slovens Creek enters the lower portion of this area, which altogether extends for about a mile and a quarter. For the remaining three miles, from the entrance of Slovens Creek to the Waimakariri, Broken River is closely confined, nearly always bounded by a rock wall on one side and a shingle bank, in a few cases grass covered, on the other.

A length of about six miles of river, extending from a point shortly below the railway-viaduct, one mile below the entrance of Slovens Creek, to a point a mile above the entrance of Winding Creek, was chosen for an observation area. Reaches of the river in this area are shown in Plates I and II. It fairly represented the predominant types of stream bottom noted in the river. Generally throughout this area the stream is shingle and boulder bottomed. Nowhere is the stream mud-bottomed. The size of the bottom material varies considerably in different reaches. Stones in the bottom material were frequently loosely cemented in very fine material consisting in part of fine yellow clay. The degree of cementation varied greatly. In one reach, where the bottom comprises small stones, grit and sand, but little, if any, finer material, considerable scouring took place when the river was at low level. Where bottom material is not loosely cemented it usually varies in size in accordance with the rate of flow.

Broken River varies in width from about 20 ft. to 70 ft. and in average depth of cross-sections, from about 10 in. to 60 in. Deep holes occur where, as is not infrequently the case, the river flows against rock bluffs. In the more open flood bed they seldom occur.

Marginal surface vegetation is entirely lacking. After periods of low water a scanty growth of brown diatomaceous matter extends over most of the more stable bottom, increasing in density in marginal and slacker waters. Filamentous algæ are usually confined to marginal belts of about 5 ft. in width, showing a tendency to spread farther in slacker reaches. In 1932 a range in water temperature of from 2° C. to 19° C. was noted, mid-July proving the coldest time. In 1933, owing to exceptional conditions, the lowest temperature was recorded in June, and, generally, temperatures during the incubation-period were much higher than they normally are. The mean monthly temperatures for portions of the years 1932 and 1933

PLATE I.—Broken River, showing the wide flood-bed above the bridge. Slovens Creek enters immediately below the bridge.

PLATE II. The lower end of the observation area in Broken River.

are shown in Table 1. The material on which these are based is meagre, consisting of eighteen readings in 1932 and sixteen in 1933.

Table 1.—Mean Monthly Temperature, in Degrees Centigrade.

Year.	May.	June.	July.	August.	September.	October.	November.
1932 ..	6·6	4·1	3·1	7·0	6·00	15·0	19·0
1933 ..	7·0	2·75	5·5	8·0	10·25	13·7	17·0

Flooding in Broken River is the product of north-west weather, although not all north-west weather causes freshes. In summer—say, December, January, and February—the stream is usually low and clear, but in autumn—say, March, April, and May—rainfalls in the headwaters cause floods, though usually of a lesser severity than in the spring. June, July, and August normally see the river at a low level, while snow falls and lies on the high country and generally the ground is frozen. Spring rainfalls, which are accompanied by a thaw, and which usually start in early October, but sometimes in September, are accompanied by the severest flooding occurring during the year. Sudden rises of 3 in. or 4 in. are usually accompanied by turbidity, and Broken River, in the springtime, is apt to remain so discoloured for several weeks on end. Heavy floods—rises of 3 ft. or more—are unusual even in the spring. The year 1932 showed normal conditions on the stream, but winter and spring conditions in 1933 were altogether exceptional. Mr. J. H. Kidd, whose sheep-run is on one side bounded by the lower portion of Broken River, writing from fourteen years' experience, states that he has never before known severe floods to occur in the winter. The winter of 1933 saw the moisture which would normally have fallen as snow fall as rain. Atmospheric temperature throughout was mild, severe frosts were lacking, and the thawing of such snow as did fall was almost immediate, instead of being, on the higher country anyway, delayed to the spring. There was a consequent absence of severe flooding in the spring. During the incubation period of quinnat-ova water turbidity was a frequent occurrence. In the second week in July an exceptionally severe flood swept the river. A rise of 4 ft. 9 in. was noted in a portion, where the depth at normal level was about 18 in.

Winding Creek.

At the confluence of Winding Creek and Broken River the relative volumes of the two streams would be in the neighbourhood of 1 : 3 respectively. Winding Creek is a stream of a very different character, being a lake and spring fed stream of a very uniform volume and temperature and one in which flooding, or any turbidity, is quite exceptional. Lake Pearson, which it sometimes drains, is subject to considerable rises and falls in level. During the period covered by these observations no surface water was entering Winding Creek from it. Observations were confined to the lower five miles and a half of water, no salmon being seen above this area.

This length of water is best considered as divisible into two sub-areas. In the upper one, for one mile and a half, the stream pursues a remarkably sinuous course, through a broad and fairly flat tussock and rush clad depression between Broken Hill and the stepped plateau out of which Mount St. Bernard rises. In the lower one, with a considerable straightening of course and a marked increase in velocity, it flows down to Broken River

through a gradually narrowing gully. In the upper reach the bottom consists of stones, nearly all of less than 3 in., loosely cemented in fine material much of which is yellow clay. The stream averages about 15 ft. in width and is confined to grassed and undermined banks rising 1 ft. to 2 ft. from the water surface. The current is nowhere sluggish as the stream pursues a course, over a succession of rapids about 10 in. deep, which are separated, at every few chains, by corner holes of up to 5 ft. in depth. Marginal surface growth is lacking. Odd small patches of *Elodea canadensis* are found rooted in small silt deposits in back eddies of holes. A very

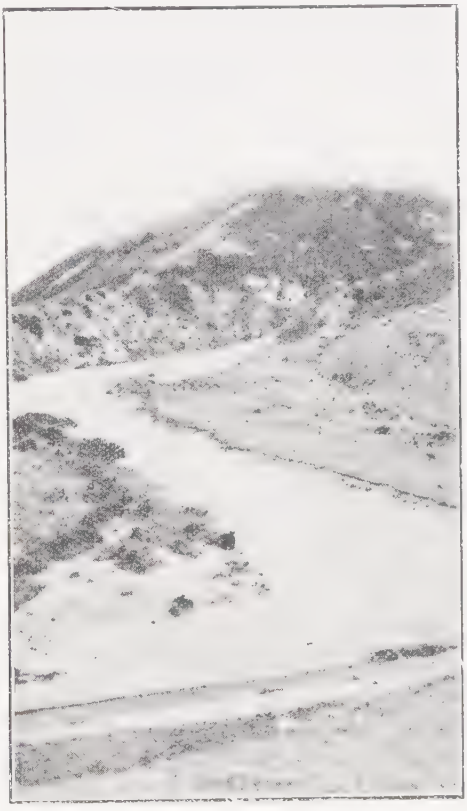

PLATE III. The storm-water course coming off Broken Hill into Winding Creek. Before the storm of July, 1933, the course of Winding Creek followed the foot of the hill.

prolific growth of brown diatomaceous matter covers the stones on the bottom in both winter and summer, appearing to be more dense in the winter than in the summer.

The entrance of a very steep flood channel at the north-eastern extremity of Broken Hill marks the commencement of the lower area. The rate of flow shows a general increase throughout this reach. The stream remains fairly strictly confined between banks which increase in height from 1 ft. to 4 ft. or more as Broken River is approached. Bank vegetation changes,

from grass and tussock to shrub growth and finally to bush, for the final three-quarters of a mile, where the valley narrows and the hills fall fairly steeply down to the stream. Towards the mouth the fall of the hills is unbroken by marginal flats such as are found higher up. At a few points bluffs of crumbling rock obtrude. Holes of any depth rarely occur, and this reach really comprises a series of rapids of generally increasing velocity. From stones up to 8 in. at the top of the lower reach there is, before any great distance is traversed, an increase in many localities to boulders of up to 3 ft. and 4 ft., which frequently protrude above the surface. All bottom material is loosely cemented. In the boulder areas, boulders are not jammed closely together, but are separated by a mixture of loosely cemented small stones in which redds are made. There are innumerable small submerged deposits of grit and silt behind the boulders where the stream flows through the bush. Generally the amount of fine matter on the surface of the bed there is greater than in similar boulder areas higher up. There is a variation of about 3° C. during the year in water temperature at the bottom as against 0·25° C. at the top of the lower reach. Both reaches seemed equally attractive to spawning fish.

Normally Winding Creek does not flood at any time of the year. Exceptional conditions in 1933 caused, on two occasions, intense turbidity, accompanied by a general rise of 4 in. Mr. J. H. Kidd states that only once previously has he known Winding Creek to be discoloured. On the 15th May, 1933, north-west rain, falling on early snow on Mount St. Bernard and Purple Peak, caused a small landslip of clay into a flood-channel which courses steeply down and, under exceptional conditions, reaches Winding Creek above the highest point to which salmon are observed to go. Two months later a much heavier rainfall from the same quarter caused further slips into this flood-channel and also caused the large storm-water course, mentioned as marking the upper reach from the lower reach, to discharge a considerable quantity of stones into Winding Creek. The extent of the latter deposit can be seen in Plate III.

Slovens Creek.

The extent of spawning of salmon in Slovens Creek does not justify any lengthy description of the lower portion of that stream. Briefly, it carries about half the volume of Winding Creek, has a temperature variation similar to that of Broken River, normally floods with heavy north-west rain, and has a bed similar to that of the lower reach of Winding Creek. The spawning of quinnat is limited to the lower one mile and three-quarters of water, fish not climbing the falls at that distance from the mouth.

The Run of 1933.

Quinnat were first observed by Mr. J. H. Kidd in Broken River in 1922, then in very small numbers. He considers that there has since then been a marked numerical increase and that, despite fluctuations, they still show some tendency to increase. From observations made on Winding and Slovens Creeks, where the number of redds could be ascertained fairly accurately, and from observations on the lower reaches on the Broken River where the passage of Winding Creek fish, as well as an occasional water turbidity, made a very accurate tally impossible, it is considered that the run of quinnat in 1933 in the Broken River system would be somewhere between two hundred and three hundred pairs.

The 1933 run in point of numbers compared favourably with those of the preceding three years.

Fish were first observed in the Waimakariri River at Staircase on about the 20th March, and in Broken River, one mile higher up, on the 10th April. It is not suggested that it normally takes salmon three weeks to cover this distance, but rather that either the fish seen at Staircase at that date were not destined for Broken River or that, if they were, conditions were unsuitable for them to enter earlier. Actually the river was very low and clear over this period. Fish continued to enter Broken River until the 26th May, the heaviest runs entering during the freshes. No difference was noted in the average size of fish comprising successive runs. Fish were already making redds on the 13th April, and a live, spent fish was taken on the 16th April. The first dead fish to be picked out were found on the 13th May, through freshes occurring before that date had probably carried away some earlier dead. No live fish were observed after the fourth week in June. In 1932 fish were first noted in Broken River on the 10th April, and six redds and seven live quinnat were counted in the lower three miles of water on the 18th. The first spent fish were seen on the 29th April, and the last live fish on the 30th May. The peak of spawning activity was at about the end of April. Owing to freshes it was difficult to fix the peak of the 1933 run very accurately. It appeared to occur between the 20th and 30th April. Netting returns at the Waimakariri mouth that year showed the presence of the maturing fish in tidal water from 19th January to 6th April. Half the total catch was landed by 15th March. Observations in Broken River showed the presence of live, mature fish for about six weeks and a half, with a peak in numbers of unspawned fish towards the end of April. If it is safe to assume that fish destined for the Broken River were fairly represented in netting returns, it seems that in the average case the upstream journey of over fifty-two miles occupies about seven weeks and a half. Spawning may be completed in as little as about three days. Life on the redds is usually limited to about three weeks. Observations on particular fish confirmed the more general impressions already given as to the extent of life on the average redd. The foregoing data as to the duration of the runs and time occupied in spawning are also applicable to Slovens and Winding Creeks. In the case of Slovens Creek, however, entrances of fish took place only during freshes: this was probably attributable to the shallowness of the mouth of the creek at normal water level. In 1932 Slovens Creek flowed for three hundred yards or so down the bed of Broken River before entering the stream, and carried at this point only 2 in. or 3 in. of water. No fish were observed to enter it, although they had entered in previous years when the mouth was deeper. In 1933, with a view to facilitating the run of fish, a pilot channel was cut from a higher point in the Broken River bed to allow waters of that stream to flow down and meet Slovens Creek at the point where it turned at right angles and flowed down Broken River bed. When, subsequently, Broken River flooded, this pilot channel opened considerably, and the combined flood waters gave a sufficient depth of water, in the previously very wide and shallow area, to enable fish to enter.

Although there were exceptions, generally earlier running fish spawned higher up Winding Creek than did those which entered later. This was not because all available spawning-areas in the upper reaches had been previously utilized.

From forty-seven sets of scales, along with measurements of quinnat taken in the Broken River System, Mr. A. W. Parrott has kindly supplied the writer with the following data :—

Table 2.

Locality.	Stream Type.	Ocean Type.
Winding Creek	17	10
Broken River	11	5
Slovens Creek	4	0
	32	15

Age-groups are designated by two numbers (*e.g.*, 1/3) indicating the duration, in years, of stream and ocean life respectively.

	Age-groups.					
	1/2.	1/3.	1/4.	0/2.	0/3.	0/4.
Winding Creek	6	10	1	..	7	3
Broken River	..	11	..	..	4	1
Slovens Creek	..	4	..	..	.	.
Totals	6	25	1	..	11	4

Age-group.	Average Length of Age-groups.		
	Winding Creek.	Broken River.	Slovens Creek.
	In.	In.	In.
1/2	24·5	..	..
1/3	30·9	32·25	30·2
1/4	41·5	..	..
0/3	29·7	30·6	..
0/4	37·5	39·0	..

Choice of Spawning-areas.

In preparation for anticipated runs, bundles of marking-stakes for redds had been deposited at intervals along the banks of the thirteen miles of water where observations were to be carried out. The area in Broken River, where most preparations had been made, was entirely neglected by spawners. This area, in the vicinity of and above the entrance of Winding Creek, had a bottom consisting of the cleanest shingle observed in the stream. It was in portions of this stretch that the "flow" of the immediate surface material of the bed was noted subsequently at times of low water. The bottom lacked diatomaceous growth at this point. In the stretch lying from Winding Creek down to the Gorge below the coal area, where the bottom consisted largely of stones from 4 in. to 12 in., and in parts of large boulders to 5 ft. cemented in very fine material, no redds were noticed, and the lack of spawning-activity presumably was due to the unsuitable nature of the bottom material. A survey of half of the short gorge did not disclose the presence of any redds. Although bottom material in it was

commonly of suitable size it lacked diatomaceous growth and doubtless was subject to much movement in flood-time. From this gorge, down through the wide flood-bed area and on until the downstream limit of the observation area was reached, intensity of spawning was fairly uniform. With very few exceptions redds were made in positions where it was obvious, from the growth of diatoms, that normal floods would cause little disturbance of the bed. Where current decreased and the river spread over a wider course redds would be made out nearly to the centre of the stream. Where the current was swifter, and disturbance by floods of the bed in the centre was to be expected, spawning was confined to the slacker, diatom-growing marginal areas. Although the spawning-reaches might be bedded by material ranging up to 3 in. or even 6 in., with occasional large boulders—for a variation was apparent—very generally such areas had two features in common—(1) some degree of cementation of the bottom material. (2) a covering of diatomaceous matter. In this stream, where a considerable range of types of bottom material was offering, no salmon chose to spawn in clean shingle. In Winding Creek, where the bed generally fulfilled both these requirements, size of material in the bed alone appeared to govern the choice of sites for redds. Analyses of material comprising two of these redds are given in a subsequent section of this paper. It is sufficient to note here that practically all the material in redds was of less than 3 in., although in many redds odd stones of considerably larger size were met with. Such larger stones ranged up to 24 in. in diameter. Redds were quite frequently made in small deposits of fine material in reaches where much of the bed consisted of boulders of from 10 in. to 36 in. Where the material separating such boulders consisted of coarse grit and finer materials no redds were made.

Spawning.

It was unusual to see a male in company with a female when the making a redd was just commencing, usual when redd-making had advanced a little, and again unusual when the redd was nearing completion.

There was little doubt that males move on and mate, if possible, with successive females. Indeed, the use of the word "mate" is apt to be misleading, and it is better to say that males endeavour to fertilize the eggs of successive females. Redd-making is solely the province of the female fish. Observations on this point tally with those later recorded of brown and rainbow trout. The observations of Rutter (*loc. cit.*) on Sacramento River quinnat are recorded as follows:—

"*Spawning Habits.*—Salmon in spawning usually take up a position at the upper end of a riffle where the current is strong and where there are gravel and cobble stones, among which the eggs may lodge. After selecting the place the female extrudes a few eggs and then moves away. The male immediately takes up her exact position, or perhaps a point 1 ft. or 2 ft. downstream from it, and extrudes a small quantity of milt. In about five minutes the process is repeated, the female always taking up the position first occupied. This they continue day and night for over a week, usually nearly two weeks. I have observed salmon spawning at night, but have never been able to watch one pair until spawning was completed. Branded salmon No. 91 previously referred to was only eight days in spawning, although some eggs had been extruded before it was taken. Two weeks is the spawning-time usually assigned by persons living in the vicinity of salmon-streams, which is probably about right.

"On account of the difficulties in seeing eggs under water it has been impossible to determine the rate at which ova are deposited. The motions of the fish show just when ova are being extruded, but observations at a distance of about 5 ft. with the aid of a field glass have failed to disclose the eggs.

"The female at irregular intervals turns over on her side and digs her tail into the gravel. If the gravel is fine there is often a considerable hillock thrown up, leaving a hole 6 in. or 8 in. deep and 2 ft. across. This digging is probably not for the purpose of covering the eggs, nor to make a space for them to lie in, but by the violent exercise to loosen the eggs from the ovaries. If the purpose were to cover the eggs it would be repeated every time any were deposited. Gravel does not drift so far as the eggs, and if such were the purpose it would not be accomplished. Besides, it is almost impossible to cover eggs with gravel; the eggs, being almost as light as the water, slide away from the gravel. More than that, a covering of over an inch of even fine gravel kills them The hillock, by forming an eddy at the bottom of the stream, prevents many eggs from floating away and being devoured by other fishes. The 'nest' can hardly be made as a place for the eggs to lie in, for the current always carried them below it.

"The presence of the other sex is not necessary to excite either to spawning-efforts. I have seen the female spawning alone at Battle Creek fishery, and other persons have reported similar observations from other places. In September, 1900, I saw a male spawning alone near Sims, the female having been killed by sportsmen in order to get trout-bait. Like observations have been reported by other persons."

On the point of non-burial of ova Calderwood (*loc. cit.*) said that he understands that the eggs of the genus *Oncorhynchus* are not covered so completely as the eggs of the genus *Salmo*. If the statement of Calderwood, which on this point tallies with Rutter's, is reliable, and Babcock's statement that "Eggs not covered by several inches of sand and gravel, are either consumed by active aquatic enemies, or destroyed by vegetable moulds," has any general application, then perpetuation of the species would scarcely be possible. Again, if non-burial, or even burial at a lesser depth than the ova of the genus *Salmo*, is the rule in North America, it is clear that either conditions there do not permit of a substantial burial, or the quinnat in New Zealand has changed from a very poor redd-making fish to a very efficient one.

In the Broken River system it was found that, in the type of bottom material indicated, the female quinnat worked slowly upstream, uprooting bottom material to a depth of 12 in. to 18 in. The size of such uproots was from 5 ft. to 10 ft. long by 2 ft. to 3½ ft. wide. The deposit of disturbed water-borne material, extending for some feet below the redd, gave the initial impression that the redds were much larger than they subsequently proved to be. A longitudinal section of a typical redd would show a pit of loose material in a bed of partially cemented matter. The firm bottom of the redd would increase in depth below the surface of the surrounding stream-bed from the top end to a point about two-thirds down the excavation, and from there on the redd-bottom would rise fairly sharply. The surface of the stream-bed so disturbed would show a slight depression at the top, and thereafter a steadily rising mound, reaching a maximum height shortly below the point of maximum depth, and thereafter falling more steeply until bed-level was again reached shortly below the point of commencement of the redd. The material at the upstream end, and

also along the bottom of the disturbed area, is the heaviest in the redd, lighter material being generally farther down stream and higher up in the vertical section. Practically all the fine "binding material" is carried down by the current. Permeability of the material which fills the depressions is much greater than that of the surrounding bed. Ova were found almost exclusively in the bottom 4 in. of material in the redd. It is considered that over 99 per cent. of the ova were in this definite egg-bearing stratum about 12 in. to 16 in. below the surface of the surrounding streambed.

Observations on the Broken River system differ from Rutter's on many points. Rutter admits that observations made with binoculars from a distance of 5 ft. failed to disclose eggs being shed. Yet he interprets a movement as an ova-shedding movement; states that fish shed "a few" eggs at a time; fixes the time required for complete spawning, and states, that "the nest can hardly be made as a place for the eggs to lie in, for the current always carried them below." He stated, without giving grounds for such an opinion, that "a covering of over an inch of fine gravel kills" eggs. Indeed, he admits that when he "dug" out five or six nests, he obtained thirteen ova, of which eleven were alive.

No night-time observations on quinnat were made in the Avoca region, and the observations here recorded were all made by day. The finding on the 15th April, 1933, of freshly taken undigested quinnat-ova in the stomachs of all of five trout, taken at intervals during the day, suggests it as possible that spawning may occur during the day. It is equally possible that these ova were shed by fish in transit. It was noted that at the commencement of the making of a redd the female was generally unattended by a male. As the pit was deepened and the extent of the disturbed matter increased, a male was usually seen in attendance. From the commencement of redd-making on, even until in extreme cases as much as a week after the male had ceased to attend on the female, the female might be seen making movements of the kind described by Rutter. The frequency of such movements decreased markedly after about the first ten days on the redd. The female, pivoting from the head-end, would swing her body round to an angle of 30° to 90° from the current, and would make a series of violent flections, during which fine disturbed matter was observed to drift away. During these movements the fish would be partially on its side, with body arched so that the mid portion was higher in the water than head or tail. No flow of ova was witnessed. It was noted, in the case of a partly made redd in Winding Creek, that, although a patch about 3 ft. square had been dug to a depth of nearly 18 in., less than a dozen ova had been deposited in it. Subsequent examinations of completed redds showed that it was not unusual to find that as much as a length of 4 ft. of material at the lower end of large redds had been turned over without deposition of ova. This movement is definitely a redd-making movement. It is improbable that ovi-position occurs then. After making such a movement the female would resume its resting position over or in the basin. In this latter position the female was not observed to make any unusual movement. When a male was in attendance it would generally within a space of one minute following the female movement, take up a position for a few seconds, with its snout approximately opposite the vent of the resting female. In the case of brown trout it was observed that, on the male taking up such a position on the redd, it made a movement that is best described as a convulsive shiver.

Because of the rippled water surface, such a movement on the part of any of the several male quinnat observed would not have been noticed.

The pits in the redds, observed during the occurrence of what was assumed to be spawning, contained in their bottoms stones above the average size of those found in a vertical section of the completed redd. When, on subsequent disruption, a similar basin or pit was formed it was found that disturbed ova showed a marked tendency to linger in it, and often to collect at the *upstream* side of it. It was further observable that ova circled round the basin in ever-reducing number as many dropped or were carried into crevices between stones in the bottom. They were remarkably similar to beasts possessing motive power, and it appeared almost as if they ran about looking for suitable hiding-places. In disrupting redds it was usual to find that ova had collected largely underneath the *upstream* ends of the bigger stones in the bottom of the redds. Such a distribution indicates that the current in the bottom of the pits of partially made redds, when ova are being shed, flows in an upstream direction. This view was confirmed by the introduction of potassium permanganate crystals into the lower end of pits of partially made redds. It was found that, while water passes rapidly downstream over the surface of the pits, there is remarkably little movement of water in the pits themselves. Such current as there is in the pits travels slowly in an upstream direction—that is, in an opposite direction to the current passing over the pits.

It is convenient at this point to consider what at first sight appears to be a conflict of observations. Eggs lodge in the redds, while stones of equal and greater size and much greater specific gravity accumulate farther downstream than the eggs do. It is not known for certain why this should be, but the following seems a very probable explanation: When the female attacks the upstream wall of the basin her movements may have the effect of thrusting the material dislodged up into the rapid current passing over the basin, with the result that only the largest stones sink to the bottom of the pit. When eggs are extruded the vent of the female may be below the swift-flowing surface water and in the comparatively dead water of the pit. If this explanation is accepted—and it is the only one that explains satisfactorily the distribution of stones of different sizes and of ova—then it is probable that oviposition occurs not when the female is dislodging material, but when she returns to her resting position over the basin. In this position her vent is in the comparatively still water of the basin and not in the rapid surface water. It was shortly following the resumption of this position by the females that males were observed to take up a definite position on the redds. The fact that the position of the male is downstream a little from the female would aid, rather than hinder, the dissemination of milt in the redd, as the milt would be discharged into water flowing in a contrary direction to that of the surface water. Milt, artificially expressed from brown trout held under water on partially made redds, sank in small clots to the bottom, to be slowly disseminated by the current. No milkiness of the water in the basin ensued, as the milt was carried slowly in small quantities among the interstices of the stones in the bottom. Although the water was no longer turbid in the basins, on the several occasions when pairs of salmon were observed to take up their assumed spawning-positions, flows of either ova or milt were not witnessed. No significance whatever can be attached to this fact, however, as fish lay with the tips of their ventral fins almost in contact with stones in the bottoms of the basins. When the fish were watched, through rippled water, from the higher plane

of the bank it would scarcely be possible to see the extrusion of either milt or ova. Eggs are adhesive when shed, and there is no reason to doubt that the great majority of eggs could be covered by the dislodgement of further material without escaping from the basins. Experiments, to be described later, made with the eggs of brown trout, confirm this view. As the action of the female advances the upstream wall of the basin, material freed of practically all dirty matter is deposited on the larger stones among which eggs have lodged. The bulk of the ova are usually found from one-third to half-way down the filled-in trench from the upstream end. There was no even seeding of ova through the redds, there usually being several very dense deposits with a sprinkling of ova intervening. In these deposits which contain the bulk of the ova, a density of up to six ova to the cubic inch was not unusual. It was a general rule that eggs were held firmly in position by pressure of surrounding material a partial flattening of ova attributed to this being a very common occurrence.

In all three streams female fish were observed apparently "spawning" alone. It is considered, however, that in every case the movement was a redd-making one and not a spawning one. Of five such cases noted three redds did not appear to have advanced enough for oviposition to commence, and in two oviposition had apparently been completed. The misinterpretation of the redd-making movements might explain instances of solitary "spawning" noted by Rutter. It will be noted that his claim to have seen a male spawning alone is not accompanied by a definition of the movements made by the male.

In Winding Creek a partially made redd, not more than a few days old, was observed on the 31st May, 1933, when an exceptionally late running fish, a female, was working on it; no male was seen, either then or during two subsequent inspections, within half a mile either upstream or downstream of this spot. A sample of over six hundred ova taken from the redd of the 16th June proved to have nearly all been fertilized: they were then approximately twelve days old. On the 16th June the fish was still on the redd, and when three days later it was killed it contained only sixteen ova. It is considered that had this fish been left it would, to judge by its physical condition, have remained on the redd for another seven days at least. Solitary females, as spent as this appeared to be on the 19th June, known to have been in occupation of redds for over fourteen days have been observed making weak redd-making movements on apparently finished redds.

Females choose the redd-sites, make the redds, deposit ova when males are in attendance, and then remain on the redds for so long as strength permits them to maintain their position against the current. Occupation of the site may last for up to four weeks. The greater part of the oviposition seems to occur within about seven days. While males may sometimes remain fourteen days, or even more, in attendance on one female, their usual practice appears to be to seek successive mates. An excess of partially spent males—about four to each female—was noted to occur at the head of Winding Creek following the completion of redds lower down, of which solitary females still retained possession. Further, it was more usual to find two or even three males fighting for the privilege of sharing a redd with a female in the later stages of the spawning season than in the earlier. Where three males dispute a position it is customary for the largest to drive off the second in size, which, in turn, drives off the smallest. It is quite unusual to see the largest of three ousting the smallest.

The Efficiency of Extrusion of Ova.

Mr. J. S. Main, Fish Culturist at the Government Salmon Hatchery at Hakataramea, has kindly supplied, from Waitaki fish, the figures for the following productivity totals (Table 3).

Table 3.

Weight of Fish, in Pounds.	Number of Ova per Fish.	Weight of Fish, in Pounds.	Number of Ova per Fish.
9	2,700	15	7,300
10	3,800; 5,200	15	5,300
12	4,400	16	6,300
12	3,600	17	6,900
13	5,300	17	5,900
14	4,650	17	7,300
14	5,300	17	7,700
14	6,300	20	7,700
15	5,000	23	8,900
15	6,400		

Counts of ova retained in eight dead females and fourteen spent and dying fish taken from Broken River and Winding Creek showed an average retention of eight ova with a maximum per individual of fifty-three and a minimum of nil. It will be seen that spawning is very complete and the loss through non-extrusion negligible. Foerster(7) found in the case of sockeye salmon that spawning was very complete and over 75 per cent. of fifty-seven specimens he examined contained twenty or fewer eggs, but three dead individuals, or 5 per cent. of the total, were found unspawned. Observations in the Broken River system do not show that any female quinnat met a natural death before spawning.

Death of Quinnat.

The following comparative table (Table 4) of measurements of fish taken at the Waimakariri River mouth with the weights of dying and freshly dead spent fish in the Broken Riven system illustrates the loss in condition suffered, a loss only partially accounted for by the discharge of ova.

All fish included in the table are females.

Table 4.

Length, in Inches.	Fresh Fish (Weight in Pounds, Waimakariri Mouth).	Spent Fish (Weight in Pounds, Broken River System).
23¼	..	4
28	13·5	6·7
29	..	7
29½	..	8·2
30	11·5	7·8
30¼	..	8
30½	..	8·2
31	13·0	10
31¼	..	11·5
31½	..	10·1
32	14·2	10·7
32¼	..	12
32¾	..	11
33	16·3	10·5
34	15·7	11
35	17·5	11
37	20·3	16

Lengths in the case of the Broken River fish were approximate only, as allowance frequently had to be made for the loss of the caudal fin. The measurements of fish at the Waimakariri mouth have been furnished from the records of the New Zealand Marine Department, and lengths are to the nearest inch only.

At the time fish entered Broken River their flesh was of the usual salmon pink, but as fish of either sex spawned the flesh gradually became paler, until finally it was a dirty white. There was some variation in the physical state of different fish at the time they commenced spawning, at the time they finished, and at the time they died. Generally, as life on the redds continues, the skin on the caudal fin disappears, leaving at first bare rays, and, finally, a stumpy peduncle to which an odd ray or two are still affixed at the time of death. Other fins generally suffered in the same way, though to a lesser extent. At first scales, and later the skin on the caudal peduncle, along the belly, and on the underside of the head go, leaving exposed bare flesh of a dirty-yellow colour. In one instance *Saprolegnia* had attacked the gills of a live fish, though it was not noted to occur on any open sores on any fish. Decomposition was not always the immediate result of wear and tear suffered on the redds. A number of females, which had completed redd-making practically unmarked and were lively and which superficially appeared in fair physical order, later became affected in just the same way. They made no effort to return to the sea and, indeed, endeavoured to remain on the redds so long as they had power to maintain their positions, and even when, unable any longer to withstand the current, they were washed, tail first, downstream, they usually stopped in the first side-eddy. Nall(16), writing on the lack of parental care of native English species of salmonidæ, remarks that all interest in the offspring ends with oviposition. It does seem possible that the action of the female quinnat, which, while dying, still fights the current to retain its position on the redd, might be correctly interpreted as evidence of post-oviposition parental care. Males, though not restrained to any one spot, appeared first to push upstream in search of more females and, when eventually strength failed and they were washed down, they, too, went tail first, to stop in the first sheltering back-eddy or to strand and die in marginal shallows.

Marking and Sampling of Redds.

An endeavour was made to mark all redds distinguishable as such on, or laid down subsequently to, the 20th April, 1933. Several of the redds laid down in Broken River before that date were not marked. In Slovens Creek the similarity of colour of stones in the stream-bed with normal diatomaceous growth made redds hard to see. It was necessary there to rely on the presence of fish as an indication of the whereabouts of the redds. Attention was nearly always drawn to redds in Winding Creek by the freshly disturbed pale grey shingle, which contrasted with the darker colour of the growth on the undisturbed portions of the stream-bed. Fish were often extraordinarily hard to see in rippled water, and, save for the constant movement of the whitening tails, would have escaped notice. In the thirteen miles of water under observation a total of 104 redds were marked. Of these, 26 were in Broken River, 8 in Slovens Creek, and the remaining 70 in Winding Creek. It is considered that not less than 90 per cent. of the total redds in Winding Creek, 75 per cent. of those in Slovens Creek, and 60 per cent. of those in the observation area in Broken River were marked. Shallow scrapes, where it seemed that fish had commenced redds

and then moved on again, were noted, but are not included in the above totals. Even allowing for the fact that much of the total area of water was unsuitable for spawning, it is considered that a considerably greater number of fish could have chosen good sites. In no one case did it appear that the spawning-operations of one female interfered with eggs earlier deposited by another fish. Although it is reasonably clear from the fact that certain females were repeatedly observed in possession of their redds from the time when they commenced working as clean fish, on until little life was left in them, that many fish must have deposited all their ova in one spot, observations were not intensive enough to show whether or not fish ever made more than one redd.

The redds were marked by driving a willow wand, to which a numbered disc was attached, into the bank opposite each redd. The position of the redd in relation to the mark was noted. While, at the time, such a form of marking appeared sufficient, subsequent diatom regeneration and flood movements of surface material of bed frequently made re-identification difficult. The state of the redd itself, the number, condition, and size of the fish at first and subsequent inspections were noted. It was thus possible to ascertain the approximate date of oviposition, and, by reference to temperature records, to estimate the approximate development stage of ova at any subsequent time before sampling.

For the collection of samples of ova and alevins a net was constructed having a rectangular mouth 4 ft. by 1 ft., tapering, in a length of 4 ft., to a tube of 4 in. diameter, which continued for a further 12 in. This trap was made of fine cotton netting having about sixteen meshes to the inch. The seams at the openings at both extremities were reinforced with calico and cord, as were also the four angles of the net from the forward opening down to the end of the tubular piece. Lengths of cord, to project 4 ft., were fastened to each of the forward corners. A length of heavy iron chain was inserted in the bottom seam of the forward opening, and affixed at either entremity to one of the lower cords. One end of a length of lighter cord was fastened to the tubular tail of the net, the cord being used to secure the tail during sampling operations. The two forward cords on one side were looped close to the net to enable a 36 in. angle-iron standard to be inserted, to brace the net in the current. As it was frequently desirable not only to shift the net a few times, but also to adjust the width of the opening in working on any particular redd, only one side of the net was usually so braced, the assistant bracing the other side by passing the lower cord under the instep of one foot and holding the ends of both cords on the one side in his hands. Plate IV illustrates the net so set. A fixed or even hinged framed net proved much less satisfactory. The net described proved eminently suitable for sampling salmon redds, and in the ordinary way at least 80 per cent. of the eggs disturbed would lodge in it. While a larger net might result in a greater percentage of disturbed ova being recovered, the difficulties of bracing such a net in more rapid water would be enormous. As it was, it was frequently necessary to reduce the size of the forward aperture, for so strong was the current that the assistant could not always brace himself against it and hold the net fully open.

After a number of redds had been examined the practice was adopted of not setting the net until ova were observed in numbers indicating that the egg-bearing stratum had been reached, this to save cleaning and resetting the net. Digging was commenced, usually at a spot about half to two-thirds of the way down from the head of the redd, while the assistant stood

on the downstream side of the digger and watched for ova, which show up quite clearly, even during the disruption of dirty redds. Early experience showed that eggs might not usually be expected in the top 8 in. of material. Later no particular care was taken in opening out a patch, about 3 ft. by 3 ft. in extent, to a depth of 8 in. or so, the debris being placed anywhere to the downstream side. Thereafter digging proceeded more cautiously until eggs were seen. No material was lifted out of the water, it being, when necessary, rocked off the shovel below the surface and carried, with the aid of the current, to the downstream side of the pit. Once eggs were noticed, the mound thrown up below the pit was, so far as possible, levelled to provided a good runway for the ova. The net was then set, care being taken to make the bottom of it lie flush on the runway. The distance the net was set below the pit was determined by the current. So great was the variation over different redds that it might, under exceptional circumstances, be set at as little as 1 ft. or as much as 10 ft. below the pit. Proper setting of the net would ensure the passage into it of ova freed from

[*Photo by A. W. Parrott.*

PLATE IV.—The ova and alevin trap in use in the Selwyn River.

most of the stones and grit which lodged on the runway. Maintenance of the level of the runway ensured non-lodgment of ova behind stones in it. It was usually possible for the digger to see fairly well how many eggs were being freed. The dirtier matter disturbed, greater difficulty in digging, and a paucity of ova would indicate when the cemented bottom underlying the disturbed area was reached. The complete disruption of any redd was not attempted. In most cases it seems fair to assume, from the size of the area dug in relation to the whole, that the bulk of the ova or alevins remained. Generally a sample of a few hundred was aimed at, although, when time permitted, digging continued so long as ova came freely. Once a fair sample was obtained a move was made to the next redd. The sample sometimes represented several pockets in one redd. In general, samples were taken from sufficiently diverse positions in different redds to ensure that they were fairly representative. Where, in redds containing alevins, the bulk of the samples were taken from above the egg-stratum, digging was continued to the bottom of the redd. It will be obvious that, without

bracing the walls of the pit, it is not possible to ensure that the same area of the original ova-stratum as of the stratum up to which alevins have worked is dug. An endeavour has been made, by the manner of presenting results, to overcome objections which might otherwise validly be raised on this account. When the net contained a sufficient sample, the tail was held by the top of the aperture and raised slightly above the stream-surface; the cord was loosened and the eggs were allowed to flow into a small shallow hand-net (see Plate V). From this they were decanted into small jars and pickled in a 5-per-cent. formaldehyde solution. With alevin samples it was necessary, after letting as many individuals as possible flow through into the hand-net, to remove the trap and examine it carefully for alevins adhering to its sides. Dead alevins in particular stuck to the sides, and the remains of those long dead were particularly hard to detect. Dead alevins were separated immediately from the live and pickled separately in a 5-per-cent. formaldehyde solution.

[*Photo by A. W. Parrott.*

PLATE V.—Removing ova from the trap.

Numerically satisfactory samples were obtained from some only of the redds marked. Flood action led to the abandonment of some, insufficient marking of others, while in several cases redds were abandoned owing to the depth or velocity of water making sampling impracticable.

TREATMENT OF MATERIAL—CLASSIFICATION OF SAMPLES.

Samples were obtained in two stages, as ova and as alevins. The criteria for determining whether death had preceded collection were different in each case. Exosmosis occurred during the collection of several samples of early ova. These samples were rejected, as determinations of losses could not be made satisfactorily after formalin pickling. In water of 9° C. the peak of hatching of quinnat-ova occurs at about the forty-fifth day, the hatching actually being spread over several days, even when all eggs are fertilized at the same time. From the twelfth day on the embryo is visible through the chorion, following coagulation after pickling. Loss-determinations of samples of an earlier age were not attempted owing to the general occurrence of exosmosis. From the twenty-first day on the

pigmented eyes may be seen in the ova. It has been assumed, for present purposes, that exosmosis always rapidly succeeds the natural death of ova. The truth of this assumption affects only the fixing of the time of the loss and not the extent of the actual loss. For had pre-eyed eggs in which exosmosis had not occurred been found in eyed samples they would have been specially examined, as would also eyed ova in alevin samples. Actually no such eggs (other than infertile ones) were found, save at and immediately following eyeing and hatching respectively. As a first step, then, samples of eggs were sorted into two main categories—those in which exosmosis had occurred and those in which it had not. Eggs in the first category were then subdivided according as they were pre-eyed, eyed, or too decomposed for such appropriation. Eggs in the second category were then re-examined. Those not showing the trunk of the embryo in the case of pre-eyed ova, or eyed embryos in the case of eyed ova, or one or the other when ova were just eyeing were dissected. Those not showing any signs of embryonic development were designated infertile. Gray (*loc. cit.*) has shown that, in the case of infertile eggs of brown trout, osmotic stability decreases with age. It was noted that the same applies to infertile salmon ova. In extreme cases stability might be maintained until after fertile ova, shed at the same time, had hatched. Osmotic stability decreases early in the incubation period when eggs are fertile, and thereafter increases again until eggs are eyed. When fertilization does not take place, stability continues to decrease with age. This results in a somewhat paradoxical position when redds of about seven days old are disrupted. The apparently dead eggs in samples so obtained are usually live ones killed by concussion while being collected, while the apparently live ones—that is, those that do not turn white—are usually infertile. It is further necessary to distinguish between natural losses and ova killed in sampling operations, particularly in early samples, where resistance to concussion is low. Eggs in which only partial exosmosis had occurred at the time of pickling, or which appeared to have recently suffered exosmosis, were dissected before assignment to either principal category. The length of the embryo in relation to egg-diameter was ascertained, and if the figure so given fell within the range presented by the similar treatment of ten live specimens it was classed as live ; otherwise as dead. The number of ova requiring such treatment was very small.

A number of shells of eggs were also recovered in samples. How these come to be recovered is discussed in Appendix B, where it is also shown that they can be excluded from samples without impairing the validity of the methods, here adopted, of determining the total loss in redds.

It is practicable to distinguish live alevins from dead only on the stream-banks at the time of recovery. Even then there are difficulties. It has been assumed, and probably correctly, that only losses occurring up till and during the day prior to sampling are separable from the live. If examination were delayed until after pickling it would be impossible to distinguish previously dead alevins from those killed in redd-disruption and from the bulk killed by the pickle. It was found that a percentage of alevins, which decreased from about 25 per cent. in the case of freshly hatched alevins to practically nothing as yolk-sac absorption neared completion, was crushed in digging. The yolk-sacs usually suffered, though occasionally the embryos themselves were crushed or even cut in two. Many of those with crushed yolk-sacs were alive at the time of removal from the net. Firstly, alevins were sorted according as they were (1) live

alevins, (2) alevins obviously crushed in digging, and (3) older partially decomposed remains. A few doubtful specimens sometimes remained. Tests made suggested that rigor mortis alone was not a satisfactory criterion, but that, when accompanied by other evidence of death, it was acceptable for determination of doubtful cases. Alevins dead for twelve hours showed insufficient change for reliable determinations. It was found that no very considerable stiffening of the body occurred in twenty-four hours, but that by that time mouths gaped open; the pupils of the eyes had changed from black to greyish-white: some coagulation of the tissues had occurred (most noticeable in very early alevins): a change in pigmentation had taken place in the larger alevins, making the dead paler than the live and giving them a slightly woolly appearance (not due to *Saprolegnia*); partial exosmosis of the yolk-sacs had occurred.

Decomposition of Ova and Alevins.

Saprolegnia appeared to be the only important factor in the reduction of dead ova from a recoverable to an irrecoverable state. Insufficient is known as to the conditions suitable for its growth to enable the formulation of sound rules as to its incidence amongst dead ova. It was, however, clear in the case of trout-redds (where more material was available for this purpose) that the cleaner the redd was the more rapid was the infection of the dead ova with fungus. In hatchery-boxes it was noted that infection, visible to the naked eye, usually follows within a very few days of loss of osmotic stability. The rate of infection of dead ova under normal conditions in redds could not be accurately determined owing to the difficulty of simulating natural conditions under control. Any form of experiment which necessitated the planting in a stream-bed, for subsequent recovery, of freshly killed ova was open to the objection (1) that infection might have preceded burial, or (2) that *Saprolegnia* spores might have been introduced to the artificial redd at the time of planting the eggs. Freshly killed ova were planted in Winding Creek in perforated tin canisters containing stream-bed material. Such canisters were buried at a depth of 8 in. below the surface of the bed. The temperature remained fairly constantly at 9° C. throughout these observations. It is likely that the degree of permeability was considerably greater in these canisters than in egg pockets in natural redds. Ova, recovered after seven days, were all infected with *Saprolegnia*. A sample was definitely recoverable after twenty-three days. At fifty-five days all comprising another sample were intact when recovered, though the shells had become very flimsy. It is considered that a proportion of these ova, at such a stage of decomposition, would have been recovered from a natural redd by usual methods. Of a total of 4,426 ova, from nine different redds in Winding Creek of up to twenty days old, only two specimens were infected with fungus, one in an eighteen-day- and the other in a nineteen-day-old sample. The possibility of any correction of loss figures being necessary, on account of decomposition of dead ova, is considered remote in the case of samples from Winding Creek, where ova normally hatched in about forty-five days.

In Broken River and Slovens Creek, consequent on lower temperatures, the incubation period was much greater, and, during it, decomposition of ova, to a stage at which they were irrecoverable, may have occurred. The planting, in the same manner as ova, of freshly killed alevins showed that in Winding Creek the limit of recovery was about eight days in the case of freshly hatched alevins, about sixteen days for twelve-day-olds, and

about twenty-four days for alevins twenty-four days hatched, and that the time required for decomposition continued thereafter to increase. Yolk fragments remained much longer, but coagulated yolk is very fragile and whole yolks are seldom recovered.

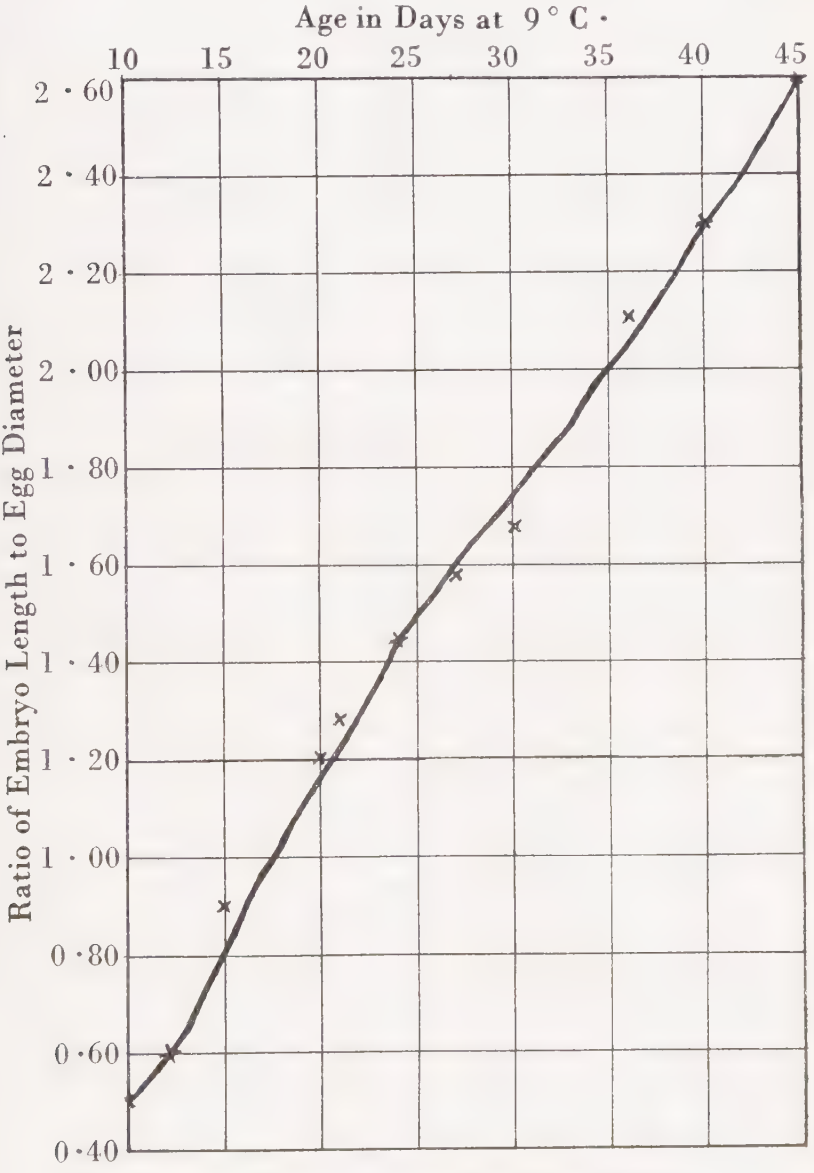

FIG. 2. Growth of quinnat salmon embryos during incubation.

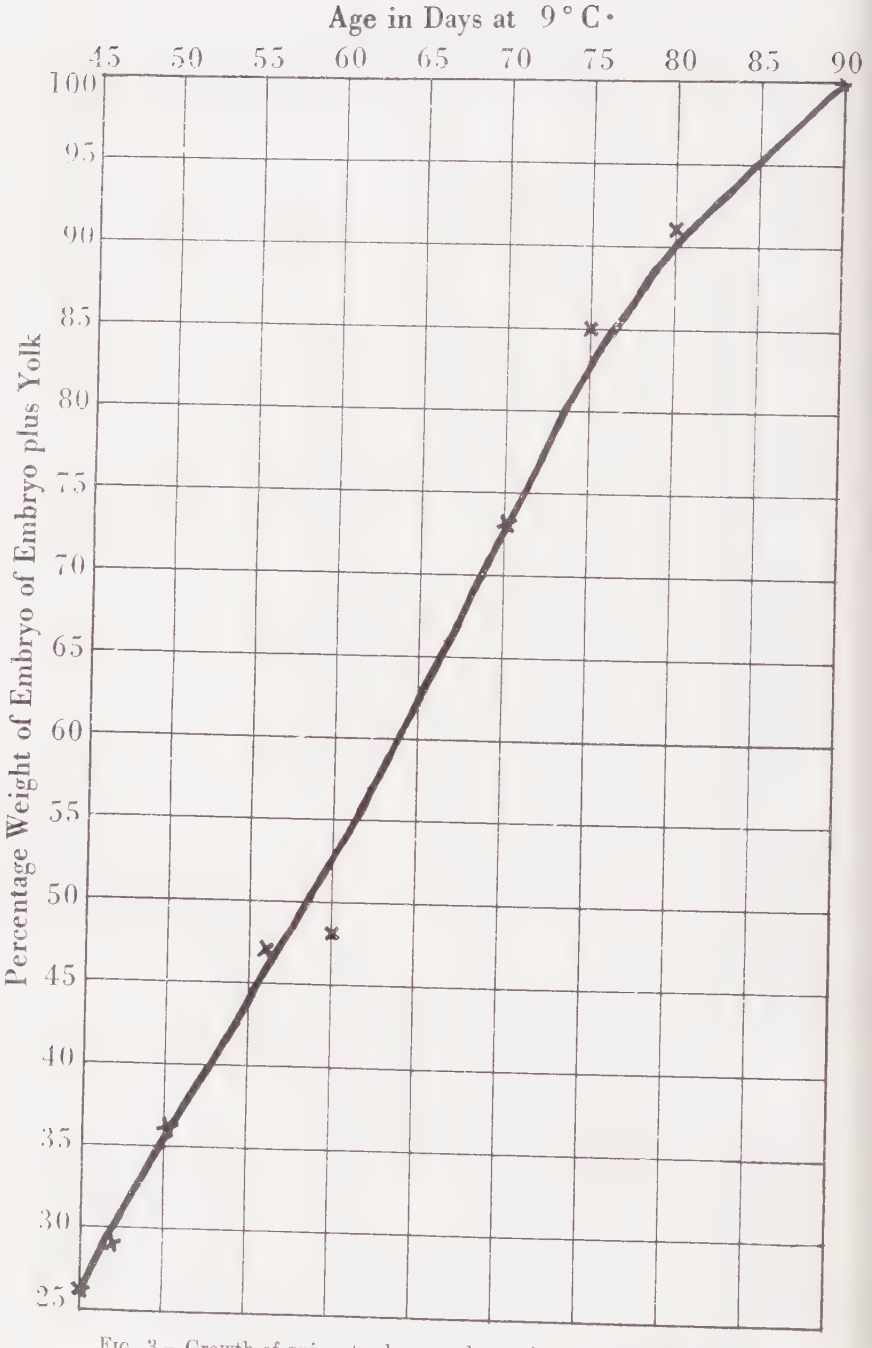

Fig. 3.—Growth of quinnat salmon embryos during alevinage.

Age-determination.

While field notes, made at the time of marking redds, offered a rough dication of the date of commencement of incubation, it was considered iat, for age-determinations, greater accuracy would result from a comparison ' ova and alevins recovered from redds with ova and alevins of known ges. To this end samples of ova and alevins of known ages were obtained, irough the courtesy of Mr. A. E. Hefford, Chief Inspector of Fisheries, from ie Government Hatchery at Hakataramea. Further samples were taken om a control-box at Winding Creek. Unfortunately, while both hatchery id control-box temperature averaged about 9° C., there was a variation ' several degrees at Hakataramea, and, during the sampling period, a ight variation in Winding Creek. This, and the fact that loss of the ontrol-box resulted in far fewer samples than were desired being taken, ises doubts as to the other than fairly general reliability of the growth irves (Figs. 2 and 3) constructed from this material. As ova varied mewhat in size it was necessary to express the greatest length of each nbryo as a proportion of the diameter of the egg from which it was taken. he average was taken of a group of each age. With alevins, the percentage et weight of embryos* to larvæ was ascertained from groups of ten of each ge. The absence of ventrally visible yolk on the alevins was not taken s evidence of complete absorption, for some yolk remained to be absorbed, ven when no longer visible on the outside.

Losses in Winding Creek.

Of the seventy redds marked in Winding Creek, samples were obtained om thirty-six. Of these, two samples were rejected on account of their umerical inadequacy, and six because exosmosis attributable to concussion uring sampling had preceded formalin pickling. The other twenty-eight edds yielded samples totalling 13,424 ova and 4,146 alevins. This material analysed in Tables 5 and 6.

Table 5.

Group.	Index No.	Age, in Days.	Total Specimens.	Total Dead.	Analysis of Dead.		
					Saprolegnia.	Pre-eyed.	Eyed.
Pre-eyed	Q.W. 1	12	634	18	..	18	
,, ..	Q.W. 2	12	604	16	..	16	
,, ..	Q.W. 3	18	860	5	1	4	..
,, ..	Q.W. 4	19	247	9	1	8	..
,, ..	Q.W. 5	20	434	1	..	1	
Eyed	Q.W. 6	24	171	3	..	3	
,, ...	Q.W. 7	24	1,196	6	..	6	..
,, ...	Q.W. 8	28	542	21	3	17	1
,, ..	Q.W. 9	30	690	17	2	14	1
,, ...	Q.W. 10	31	553	36	5	29	2
,, ...	Q.W. 11	31	737	6	..	3	3
,, ...	Q.W. 12	32	404	10	5	..	5
,, ...	Q.W. 13	32	734	27	1	24	2
,, ...	Q.W. 14	33	739	5	1	4	..
,, ...	Q.W. 15	35	371	1	..	1	..
,, ...	Q.W. 16	35	218	3	1	2	..
,, ...	Q.W. 17	36	1,422	9	2	6	1
,, ...	Q.W. 18	36	377	57	2	49	6
,, ...	Q.W. 19	40	802	4	2	2	..
,, ...	Q.W. 20	41	1,130	16	4	8	4
,, ...	Q.W. 21	43	559	39	26	5	8

* The term embryo is here used as in Figs. 3 and 6 to mean the body, not including the yoke of the levin, while larva is used to mean the whole individual (body + yolk).

In the foregoing table ova which had been attacked by *Saprolegnia* are listed separately. This is done to show the incidence of this decomposition agent. All eggs attacked by *Saprolegnia* were dead pre-eyed eggs. They have been added to the other pre-eyed dead for the ascertainment of the total loss in the pre-eyed stage.

It is obvious that the efficiency of fertilization is remarkably high. The loss from all causes in five samples which had not completed pre-eyed development was only 1·76 per cent.

It will be shown later that in redds of trout the incidence of loss is not uniform throughout pre-eyed development. Material from salmon redds is insufficient to show the normal incidence of loss in this period. Losses occurring before the eyed stage is reached can, therefore, be ascertained safely only from samples which have completed pre-eyed development. Of the 10,645 specimens taken after completion of the eyed stage, 227, or 2·13 per cent., were either unfertilized eggs or eggs which had died before reaching the eyed stage.

If sufficient samples, which had recently completed eyed development, were available for the purpose, the total loss in the eyed stage would best be ascertained from them. Most of those available are alevin samples of such an age that total decomposition might have occurred of ova which died shortly after entering the eyed stage. Further, for reasons already given in the discussion of sampling methods, there is no certainty that the true proportion of ova which have died will be recovered along with a sample of alevins. It is necessary, therefore, to estimate losses for the total period of eyed development from the known losses for portions of that period shown in Table 5. Present data indicate that the incidence of mortality is fairly uniform throughout the eyed period. This period extends from the twenty-first to the forty-fifth day—that is, for twenty-four days. The sixteen samples represent 195 days of eyed development. If each had completed eyed development, 24×16 days of development would be represented. Dead eyed ova number 33 out of 10,645. The loss per centum for the whole eyed stage estimated from this material will therefore be $\frac{33}{10,645} \times \frac{24 \times 16}{195} \times \frac{100}{1}$ —that is, 0·61 per cent.

Thus the total loss up to hatching will be 2·74 per cent.

Losses as alevins are shown in Table 6. The dead ova recovered with these samples have been excluded from the totals shown.

Table 6.

Index No.	Age, in Days.	Total Alevins.	Number Dead.	Percentage Dead.
Q.W. 22	58	190	0	0·00
Q.W. 23	62	937	9	0·96
Q.W. 24	72	103	0	0·00
Q.W. 25	73	858	202	23·54
Q.W. 26	75	290	6	2·06
Q.W. 27	78	495	0	0·00
Q.W. 28	79	1,184	0	0·00

The exact age at termination of life in the redds is not known. In a few cases free-swimming alevins about eighty-two days old have been taken at some distance from redds. At the Hakataramea Hatchery, where the temperature approximates to that of Winding Creek, feeding is commenced at the eightieth day, at which time some yolk remains (see Fig. 3). At the seventy-eighth and seventy-ninth days alevins were still about 9 in.

elow the surface of the stream-beds. Ordinarily the upward movement f alevins begins slowly and rises sharply towards the end of redd life, and, o far as could be judged, somewhere about the eighty-fifth day is the ustomary time for emergence from the redds in water of 9° C. Thus the naterial presented in Table 6 covers most of alevin life in the redds. When onsidered in conjunction with alevin-decomposition rates, already given, indicates a very low post-hatching mortality in normal redds. Abnormal onditions caused a heavy loss in Redd Q.W. 25, and also in two other of he seventy redds kept under observation in Winding Creek. These special osses are discussed elsewhere (pages 82–3).

Losses in Slovens Creek.

Of eight redds marked in Slovens Creek, samples were obtained from four. Of these samples, only two had developed sufficiently to enable satisfactory determinations of loss to be made. The two satisfactory samples totalled ,965 ova. Table 7 shows the losses in these samples. The age, in days, here is the difference between the noted approximate date of oviposition nd the date of collection. The temperature of Slovens Creek was much nore variable, and had a considerably lower mean than that of Winding Creek. For purposes of comparison the numbers of days it would have aken these two samples to reach similar stages of development in Winding Creek are given in parentheses.

Table 7.

Index No.	Age, in Days.	Age, in Days, if in Winding Creek.	Total Samples.	Total Percentage Dead.	Analysis of Dead.	
					Pre-eyed.	Eyed.
Q.S. 1 ..	38	(21)	98	2·04	2·04	..
Q.S. 2 ..	92	(44)	1,867	11·99	3·37	8·62

Reference will be made later to the effect of a flood on Redd Q.S. 2. It will be noted that in this redd losses in the eyed stage exceeded those n the pre-eyed stage.

Losses in Broken River.

In all, twenty-six redds were marked in the selected area of Broken River. Samples were obtained from six redds. Only three such samples had developed sufficiently to enable satisfactory determinations of loss to be made. Particulars of these samples are given in Table 8.

Table 8.

Index No.	Age, in Days.	Age, in Days, if in Winding Creek.	Total Sample.	Total Percentage Dead.	Analysis of Dead (all Pre-eyed).	
					Saprolegnia.	Infertile.
Q.B. 1 ..	16	(14)	126	0·79	..	0·79
Q.B. 2 ..	32	(16)	245	3·66	2·85	0·81
Q.B. 3 ..	31	(19)	492	1·43	0·61	0·82

These samples had not completed pre-eyed development. Both these samples and one of those from Slovens Creek indicate that the losses in undisturbed redds in Winding Creek are not exceptional for redds not disturbed by floods. Many other redds in Broken River were later affected by abnormal flooding. Flood losses are discussed more generally and more particularly later in this paper.

SECTION III. THE SPAWNING OF BROWN TROUT.

A. BROWN TROUT IN SLOVENS CREEK.

Description of Stream.

Slovens Creek drains Lake Hawdon and the swampy floor of a depression to the north-west of the lake. It follows a course of about twelve miles to enter Broken River. Generally it is the reverse of the normal stream in that it becomes increasingly rapid towards the mouth. The valley, the course of which the stream follows, narrows appreciably in width, especially over the last three miles. In parts of the upper nine miles the stream is bordered by swampy land.

The stream may conveniently be considered as comprising three reaches. Generally in the uppermost there is a slower current and a greater average depth than elsewhere. Holes of up to 10 ft. in depth occur. The coarser stones in more rapid portions seldom exceed peas in size. Much aquatic vegetation (*Potamogeton* and *Myriophyllum*) is rooted in very fine bed material in slower portions.

In the middle reach the course in very sinuous. Rapids, bottomed by stones of up to 2½ in. heavily covered with diatomaceous matter, are broken at short intervals by holes of up to 4 ft. 6 in. deep. Rooted vegetation sometimes grow in the holes which are found at every 20 yards or so along the course. The stones in the more rapid portions are loosely cemented in fine matter, much of which is yellow clay. The very low banks, grass and tussock-clad to the water's edge, are generally undermined, and very little marginal shallowing occurs. The width of the stream varies from 5 ft. to 10 ft., increasing to about 15 ft. in a number of short stretches where the original course was straightened when the Midland Railway was built. In these cuttings a limited amount of marginal vegetation usually watercress (*Nasturtium officinale*) grows. This reach lies between points opposite the 45-mile and 48-mile pegs on the Midland Railway-line. Its length is approximately four miles and a half. The mean height of this reach above sea-level is about 1,650 ft.

The commencement of the third reach is marked by an increase in velocity, as the stream spreads out over a wider bed, comprising stones of up to 18 in. which frequently project above the surface. After travelling thus for half a mile, the stream goes over a series of small falls, and then, for another half-mile, occupies a bed very similar to that immediately above the falls. Thereafter it enters a narrow gorge, where in parts it flows against solid rock, and boulders of up to 3 ft. occur in the bed. A tributary enters this reach. It is only in this lowest reach that portions of the bed of Slovens Creek show signs of previous flood-time instability.

There is no evidence of the frequent occurrence of heavy floods in Slovens Creek, and observations extending over the greater part of two years confirm local opinion that they are rare. Figures kindly supplied by Mr. J. K. McAlpine, of Craigieburn, near its source, show an average rainfall there of about 35 in. per annum. Very heavy falls of north-west rain alone appear to cause flooding. Even then the rise and fall are very slow, because of the amount of swampy land along the course. Marked turbidity very rarely occurs. Generally the stream takes on, to a small degree, in flood-time the tea-

lour common in peaty and bush streams. While a little peat is found ong its course, generally in the two upper reaches, the stream flows through ay. Occasionally mild winter and early spring floods occur, but serious ooding, causing turbidity, is usually limited to autumn and late spring. does not take place during the time when trout-ova and alevins are to found in redds. The extraordinary conditions which caused winter ooding in Broken River and Winding Creek (which are affected by rain ming from the same quarter) also caused very heavy flooding in Slovens reek in July, 1933. The difference of the conditions of 1933 from the more rmal conditions of 1932 is reflected in the following table (Table 9) of mean onthly water temperatures for portions of the two years. It will be noted at the later winter temperatures, July and August, were higher in 1933 an in 1932.

TABLE 9.—SLOVENS CREEK MEAN TEMPERATURE (DEGREES C.).

	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
932 ..	..	..	..	..	7·0	4·4	4·3	5·5	7·8	11·9	13·2	14
933 ..	16	13·7	14·4	9·3	7·1	4·0	5·1	5·8	7·7	11·4	..	..

THE STOCK OF SLOVENS CREEK.

The upper two reaches of Slovens Creek together constitute a partially ntrolled piece of water. The stock of trout cannot be increased naturally y migrations of fish from above or from below. Fish could leave by passing ver the falls at the lower end. Brown trout are the only introduced fish und in this region of Slovens Creek. Lake Hawdon contains both brown nd rainbow trout. Brown and rainbow trout and quinnat salmon occur elow the falls. The volume of water leaving the swampy northern end f Lake Hawdon is very small and flows for 200 yards underground before oming out as Slovens Creek.

No liberations of brown trout had been made in the upper region of lovens Creek since 1927. The stock of fish present in the angling season xtending from 1st October, 1931, to 30th April, 1932, was very largely ne product of natural spawning in that stream. Readings, supplied by fr. A. W. Parrott, of scales of fifty-two fish taken that season showed that fty had been hatched since 1927. So plentiful were trout there in ebruary, 1932, that five hours fishing by two anglers, taking turn about ith one rod, resulted in the capture of forty-six brown trout of over the then gal size limit of 9 in. For some years previous to that season a limited nd fairly uniform amount of angling had taken place, yet the stock had been t least well maintained. In the latter part of the season 1931–32 there as a marked increase both in angling intensity and in efficiency of methods mployed by anglers there. A continuation throughout the season 1932–33 f the angling intensity experienced at the end of the previous season, with me further increase in efficiency, brought about a marked decrease in he number of spawners in the winter of 1933 and in the average size and umbers of fish comprising anglers' "bags" in the season 1933–34. The umber of redds of brown trout noted in this region of Slovens Creek in the inter of 1932 was fifty-five: in 1933 the number fell to twenty-three. n increase in the legal size limit to 10 in., since made, would have had o effect on maintenance of stock in this particular case. Anglers fishing

Slovens Creek had previously made a practice of returning to the water most fish of up to 10 in. and even more. The writer, who was one of the parties responsible for the capture of over forty fish in one day in February, 1932, found it impossible, two seasons later, under equally favourable conditions, to take more than eight fish of over 9 in. in any one of a number of days. The method of angling employed by the writer in each season was the same; efficiency was virtually constant. Percival(18) has shown that in the Oreti River in New Zealand a decrease in the average size of fish comprising anglers' catches extending over a number of years was attributable to an increase in angling intensity. An increase in angling intensity and efficiency in Slovens Creek resulted, in a very short time, in a remarkable decrease in numbers of fish comprising the "bag" of the individual angler and in the productivity of the stock of fish.

The Spawning of Brown Trout.

The reach of Slovens Creek chosen for the study of the losses in redds was the middle one of the three described. Save where otherwise expressly stated, subsequent references to Slovens Creek in this section are to this reach only.

No "run" of spawning trout, in the accepted sense of the term, takes place in Slovens Creek. The distribution of redds along its course agreed very closely with the summer distribution of fish, as indicated both by angling catches and direct observations. Pre-spawning movements of varying though small extent, in point of distance, take place. It appears that these may equally be downstream as upstream according to the position of the nearest suitable spawning area. Slovens Creek is unusual in that small holes, which are the summer refuges of maturing trout, alternate with great frequency with short rapids, which provide suitable spawning areas in winter.

When redds were being commenced they were occupied by females which were almost invariably alone. Males were seldom seen in the immediate vicinity of redds until the latter were nearly ready for ova-reception. Only females were observed to move material when redds were being made. One large redd of usual conformation was very slowly made and completed, without any ova being therein deposited, by the only fish—a female—ever seen on or near it. This instance should not be confused with trial redds of small extent such as not uncommonly occurred. Towards the end of the spawning-season, when there was a notable excess of males over females on the few redds which were still occupied, redds were made in a much shorter time than earlier in the season. It seems that the female chooses the site, prepares a redd for ova-reception, and, if necessary, slows the work down to await the arrival of a male. The presence of a male is not necessary to stimulate the female into preparing a redd, but is necessary to excite oviposition.

The total period of occupation of a redd site varied from about seven days to about twenty-four days. Satisfactory evidence will later be adduced to show that a female brown trout may make several redds at one spawning. In Slovens Creek, where patches of good bottom material of considerable extent were available, bigger redds were made and more ova per redd were deposited than where the bed was of a less even nature. The actual area of stream-bed of the types chosen for spawning was only a small portion of the total area of such types available. Superficially spawning areas appeared to comprise mainly stones of up to $2\frac{1}{2}$ in. Closer examination

owed that the stones rested on and were partially cemented to an under-
ing admixture of stones of like size and finer material which contained a
nsiderable quantity of yellow clay. In the artificial cuttings, bottom
aterial was generally finer, with more clay than in the natural course.
ones on the surface of the bed in all shingle areas were covered by a parti-
larly dense brown diatomaceous growth. After disturbance, regeneration
diatomaceous matter, to such a stage that the disturbed area became
distinguishable from the surrounding bed, took place in winter within
x weeks.

In general form the redds of brown trout are like those of quinnat salmon.
size redds of trout are usually much smaller. Trout redds in Slovens
eek varied from 2 ft. to 7 ft. in length and from 18 in. to 36 in. in width.
ie maximum depth to which the bed was excavated by trout was 10 in.
d the minimum 6 in. in different redds. The great majority of redds
d a maximum depth of about 8 in.

The number of egg-pockets per redd increased with the size of redds.
ie numbers ranged from one to at least three. The pockets were very
stinct, one from another—more so than in redds of salmon. Virtually
eggs were in these pockets, usually at a depth of about 8 in. below the
rface of the redd. Later examination of a typical pocket showed forty-
ie eggs in contact on one plane.

. 4.—Longitudinal section of spawning-redd of brown trout, showing position of egg-pocket.

In making redds, the females first make holes in the stream-bed and then
ntinue to work in an upstream direction filling the portion first dug with
coarser material later disturbed. The substratum of undisturbed
terial underlying the finished redd falls steadily from the upstream end
the redd down to the point where work was commenced, and thereafter
es very sharply to the surface of the bed. The surface of the redd is
aracterized by a depression at the upstream end, from which an inclined
ne leads up to a summit shortly below the point of commencement.
e depression, which contains stones larger than the average in the inclined
ne, is 2 in. to 3 in. below the level of the surrounding bed. The mound,
mprising stones smaller than the average on the inclined plane, projects
. to 4 in. above the bed. All redds were made in loosely cemented
terial. The finished redds were basins filled with clean permeable
terial in a surrounding bed of dirty and less permeable matter. Very
mmonly a pocket could be located by digging at a point about two-thirds
the way down the inclined plane. Figure 4 shows a longitudinal section
a normal redd.

As redds aged their surfaces tended to become uniform with that of the
eam-bed. Sediment tended to lodge and to cake firstly amongst the
face material of the redds, forming a silt "crust" overlying cleaner

material. In some cases, but subsequently, silt penetrated to egg-pockets virtually restoring the bed to its original state.

Observations did not show conclusively just when and how oviposition takes place. Examination of two redds, from which pairs of fish were disturbed at night, did not disclose any eggs lying exposed to view in the pits. Trout were watched on redds through binoculars, from a distance of 4 ft. 6 in., in daytime. A movement interpreted as milt shedding was noted in each case. Activities on one redd were watched for a space of one hour and a half. This was one of the latest redds to be made and was then nearing completion. The estimated weights of the seven fish noted in the immediate vicinity of this redd were as follows:—

A = a female of 8 oz.: Approximate time on redd 80 minutes.
B = a male of $2\frac{3}{4}$ lb.: Approximate time on redd 15 minutes.
C = a male of $1\frac{1}{2}$ lb.: Approximate time on redd 40 minutes.
D = a male of 8 oz.: Approximate time on redd 50 minutes.
? = Sex ? 6 oz.: Approximate time on redd 15 minutes.
F and G = Sex ? 3 and 4 oz. respectively.

The female A was on the redd for practically the whole time. This was the only fish which disturbed any material in the stream-bed. At intervals of about a minute she would turn at right angles to the current, and attack the material at the upstream side of the pit. The exact nature of this attack was difficult to determine because of the water turbidity resulting from her movements. After each attack this fish resumed a resting position in the basin of the partially made redd. She was not observed to make any unusual movement in this position. The male B, which occupied the redd with A for the first fifteen minutes, made no movement suggestive of spawning-activity. After B left, the fishes C, D, and E endeavoured to keep A company in the redd. For short periods several fish were on the redd, but generally the largest male would drive off the next largest, which in turn drove off the smallest fish. The remaining two, F and G, did not intrude on the redd, but lay a few feet below. When B had departed, the dominating male for the time being, following on each resumption of the resting position by the female, took up a position with the tip of its jaws beside the female's vent. In such a position it would make a movement which has been interpreted as milt shedding—a movement unaccompanied by any disturbance of bottom material. This was nothing more than an exaggerated shiver extending over the whole body. The duration of each such movement would be rather less than a second. Sometimes several such movements would follow in quick succession. In making such movements the male lay in such a position that the lowest portion of its anal fin extended to within $\frac{1}{2}$ in. or less of the bottom of the pit. These male movements were independent in point of numbers of the female's movements, but they nearly always followed within 20 and at the outside 120 seconds of the resumption of a resting position by the female.

It will be shown in a later section that a remarkably high percentage of the eggs shed by brown trout lodge in the redds. It will be shown that fertilization is remarkably efficient. It is clear from the latter fact and the fact that the male is only present during a part of the time that the redd is being made that oviposition does not occur during all redd-making movements. The dense massing of ova into a very few egg-pockets of small

extent again supports this. The high efficiency of lodgment of ova in redds proves that eggs are not shed during all redd-making movements, but that they only lodge in the redd when a certain point of construction has been reached. The currents of water in partially made redds of trout are the same as those already described in redds of salmon. The question arises as to whether any eggs are shed when the female is making any redd-making movements. For the same reasons given in regard to salmon, it is considered improbable that eggs of trout are shed during such movements. Rather does it appear probable that oviposition occurs between some of such movements during some of the time the male is in attendance—that is to say, when the female is in the position described as a resting position.

No significance can be attached to the fact that no flow of ova or milt was witnessed. One would not expect to see it. In the case of the activities on the redd just described the water was usually a little turbid when the female first resumed the resting position. It was often still a little discoloured when the males made their characteristic movements. Fish of each sex were viewed from a higher level as they lay close to the bottom. In the case of the males, the agitation, during their movements, of white-fringed anal fins would have added to the difficulty of seeing milt.

Sampling of Redds and Treatment of Material.

In 1932 and 1933 spawning extended from early in June until late in July. All redds seen were marked. In the first year they totalled fifty-five and in the second twenty-three. Redds were marked in the same manner as were salmon redds. In 1933, in addition to the disk stakes on the bank, six short pegs were driven into the bed round a number of redds. The pegs were buried to a depth of 7 in. or 8 in. and projected about 2 in. In a number of cases stakes on the bank alone proved, at later dates, an insufficient guide, and redds could not be re-identified. Far more samples would have been obtained from redds had pegs been driven round all of them.

The procedure adopted and apparatus used for the sampling of trout and salmon redds were the same. Samples obtained from redds of trout were usually smaller in size. A few of less than fifty specimens, and a number of early samples collected in 1932 in which osmotic stability was lost before they could be pickled in formalin solution, have been disregarded. In 1932 all samples were preserved in a 5-per-cent. formaldehyde solution. This material was sufficient to enable losses to be determined onwards from the time when (taking incubation and alevinage as representing 100 equal units of time at a standard temperature) a 14-per-cent. stage of development was reached. Ova which had not approached this stage usually suffered exosmosis when being recovered. Material, otherwise satisfactory, usually included a few specimens of ova which had lost osmotic stability following death from natural causes. For these two reasons the percentage of ova which had been fertilized could not be determined with sufficient ease and accuracy. Throughout these investigations circumstances demanded that, so far as possible, methods should be found which would admit of speedy and reasonably accurate determinations of losses being made in the field without the aid of a microscope or other expensive equipment. Rutter (*loc. cit.*) states that when ova are treated, twenty-four hours after fertilization, with a 5-per-cent. to 10-per-cent. solution of acetic acid the segmented blastoderms of fertilized ova can be distinguished under

a microscope without resorting to dissection. For the purposes of this study it was neither necessary nor convenient to determine losses at so early an age. It was only necessary that losses should be determined at some time before decomposition made it impossible to distinguish initially infertile ova from losses occurring subsequently. The following practice was adopted for all collections of trout ova made in 1933 or later in Slovens Creek and elsewhere. Where possible ova were left until they contained embryos capable of being fairly accurately measured—that is, until they were about 15 per cent. developed. In streams where the water temperature was lower, earlier growth stages were collected than where temperature was higher. Immediately a sample was removed from the trap, all ova which has suffered exosmosis were picked out, and placed in a solution of 5-per-cent. acetic acid. A similar solution was used for the bulk of the sample, which was pickled separately. Ten live ova were pickled in 5-per-cent. formaldehyde for age-determination purposes. Acetic acid renders the chorion transparent and coagulates the embryo. Final determinations of losses were always made within twenty-four hours of collection of material. Eggs in the rough groupings made in the field were re-examined The group in which osmotic stability had been lost was sometimes found to contain a few ova which had been killed in collecting them. As with salmon-ova, the relationship of embryo-length to egg-diameter of any doubtful specimen was compared with that of known live eggs. A few infertile ova, in which osmotic stability had been maintained, were sometimes found in the bulk of the sample.

Armistead (*loc. cit.*) noted that the blastodiscs of infertile eggs disintegrate with age. In samples of older ova, eggs occurred in which neither embryo nor blastodisc could be detected. Such eggs, and any containing blastodiscs, taken in samples in which specimens contained distinguishable embryos, have been classed as infertile.

Dead ova were classified according as they were (1) infertile, (2) pre-eyed, or (3) eyed. Eggs, so decomposed that the separation of pre-eyed from eyed ones would not have been possible, were listed separately. Where samples contained pre-eyed eggs which had suffered exosmosis, the eggs placed in the infertile category were not necessarily all the infertile eggs.

The growth-curves of embryos during incubation and alevinage are shown in Figs. 5 and 6 respectively. The conditions, under which material used for the construction of these curves was kept, are described and the soundness of the curves constructed is discussed in Appendix C. As material, less than 10 per cent. developed, has been used only for the determination of the efficiency of fertilization, its appropriation to points of development up to that stage has not been necessary. The stages of development of samples from Slovens Creek have been ascertained, as were the stages of material from salmon redds in Winding Creek. Because of the variable temperature, however, of Slovens Creek, it has been necessary to express the degree of development of any sample as a percentage of the total development. Such a course was unnecessary in Winding Creek, where on account of the relatively constant temperature any two samples reached a given point of development in the same time. In Slovens Creek the time taken to reach any point varied from redd to redd, and the latter half of development took a much less time in a rising temperature than the first half did.

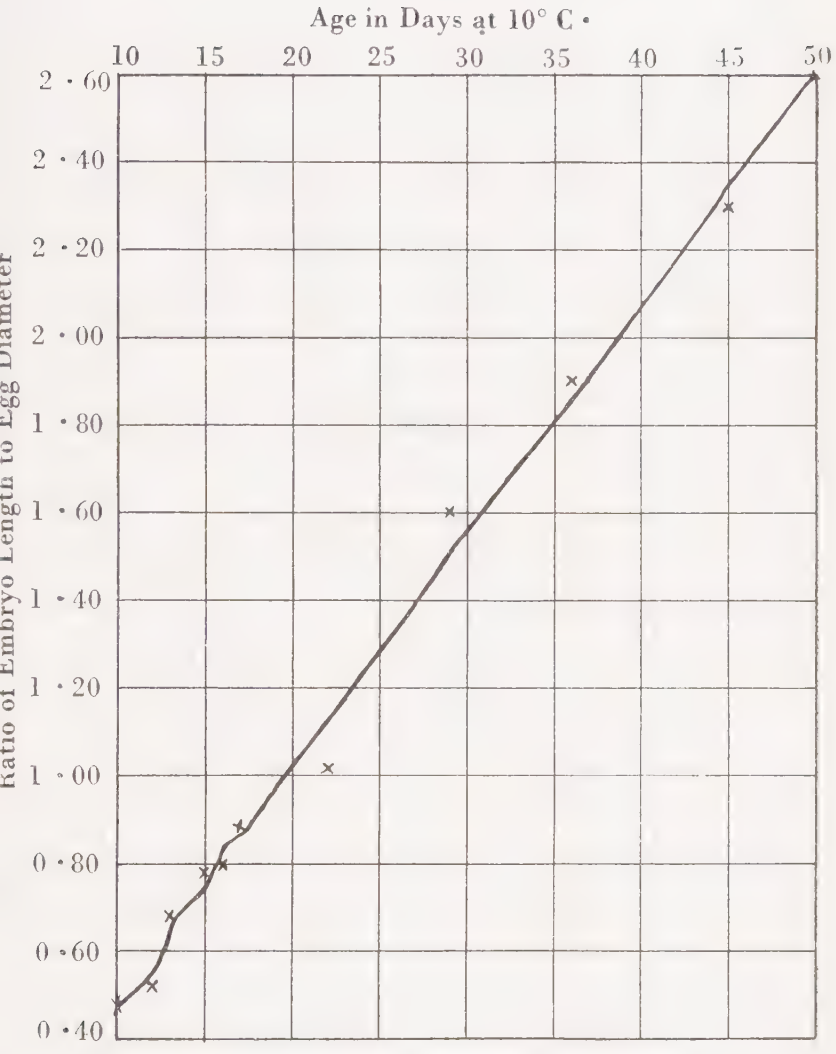

Fig. 5.—Growth of brown trout embryos during incubation.

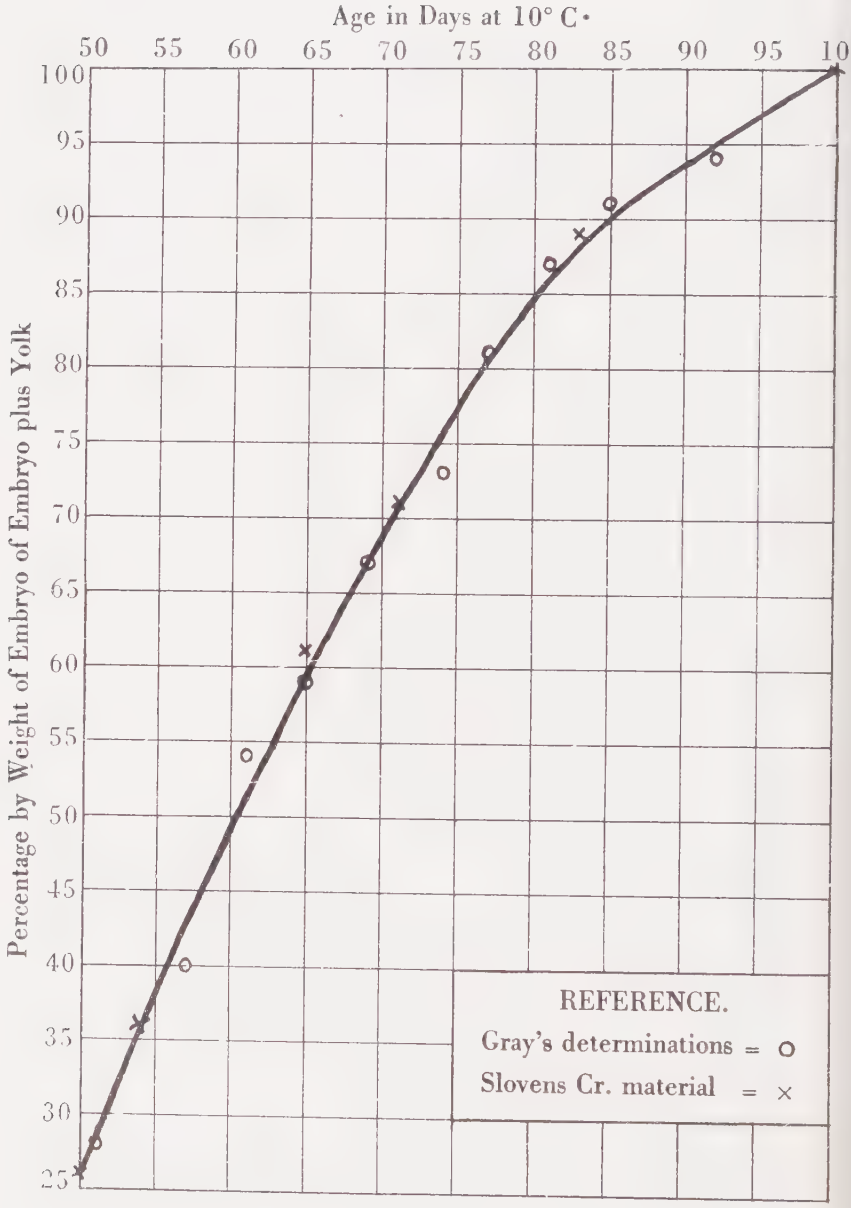

Fig. 6.—Growth of brown trout embryos during alevinage.

Losses.

Material collected from redds of brown trout in Slovens Creek in 1932 and 1933 is analysed in Table 10.

Table 10.

Group.	Redd Index.	Total Sample.	Percentage of Development.	Total Dead.	Analysis of Dead.				
					Decomposed.	Infertile Ova.	Pre-eyed Ova.	Eyed.	Alevins.
Pre-eyed ..	1	1,183	Under 10	10	..	10			
	2	326	Under 10	1	..	1			
,, ..	3	462	10	3	..	3	..		
,, ..	4	841	12	3	..	2	1		
,, ..	5	182	13	1	..	1	..		
,, ..	6	101	14	3	..	..	3		
,, ..	7	395	14	59	..	..	59		
,, ..	8	645	15	22	..	1	21		
,, ..	9	297	25	9	..	..	9		
	10	387	26	16	..	..	16		
Eyed ..	11	219	27	4	..	..	4	..	
,, ..	12	566	28	150	..	..	145	5	
	13	759	29	74	35	..	32	7	
	14	347	33	13	8	..	5		
	15	352	34	6	2	..	4		
	16	429	35	12	5	..	7	..	
	17	262	35	15	3	..	7	5	
	18	417	37	9	8	..	1		
	19	414	37	28	13	..	12	3	
	20	302	37	3	..	1	2		
	21	238	42	2	..	2	..		
	22	111	45	109	63	..	46		
	23	414	48	3	1	..	2		
	24	236	50	8	3	..	1	4	
Alevin ..	25	556	51	424	73	..	327	21	3
,, ..	26	288	53	183	18	..	154	9	2
	27	309	58	153	16	..	51	84	2
	28	234	61	74	3	..	34	34	3
	29	228	62	203	10	..	159	34	
	30	595	65	70	35	..	21	6	8
	31	224	65	187	36	..	101	50	
	32	98	68	82	22	..	35	25	
	33	168	69	38	20	..	18		
,, ..	34	81	71	56	19	..	29	7	1
,, ..	35	280	75	54	32	..	14	8	

The four samples from pre-eyed redds suitable for the purposes show that fertilization is a very highly efficient process. The loss through infertility is 15 out of 2,153, or 0·69 per cent.

The interpretation of the rest of the data is very difficult. In Winding Creek there was a marked uniformity of environmental conditions. Water-temperature was relatively constant; the material comprising redds was very uniform in composition. In Slovens Creek, however, there was no such uniformity. Different redds were made at different times and were subjected to different ranges of water temperature. What is most important is that they were made in very different types of material. The possible adverse effects of different types of environment could not be anticipated before collecting commenced. It was not until many redds had been disrupted

that the full extent of the differences became apparent. Sampling in Slovens Creek was fair in that all spawning-areas were sampled and the number of samples obtained from each area was representative of the intensity of spawning in these areas. However, the proportions of samples in each main development group taken from heavy-mortality areas and from low-mortality areas were not constant. If they had been, the percentage of pre-eyed dead could not have been greater in alevin samples than in eyed ova samples; the greater age of the alevin samples would have resulted in more decomposition of dead pre-eyed eggs. It is clear from Table 10 that the samples recovered in the alevin stage had suffered heavier losses in the pre-eyed stage than had those collected in the eyed stage. The procedure adopted for estimating the total loss in the salmon redds cannot therefore be followed here. The loss in the pre-eyed and eyed stages must be estimated from all samples, whether eyed ova or alevin, which had completed pre-eyed development. Every effort was made in sampling each alevin redd to ensure that as far as possible the same area of the ova-stratum was dug as of the overlying material in which alevins were found. This was much easier to do in the smaller and relatively shallow trout redds than in the salmon redds.

Dead ova too decomposed for appropriation with certainty to either the pre-eyed or eyed dead category have been separately listed in Table 10. Even apart from these eggs there is a marked preponderance of pre-eyed over eyed dead still distinguishable in the alevin samples. It is reasonable to suppose that those ova which died earliest would have contracted *Saprolegnia* and reached an advanced stage of decomposition before eggs which died later. For the estimation of the total pre-eyed loss, these decomposed ova and infertile ova have been considered with the other pre-eyed dead. Including unfertilized ova, 1,639, or 20·16 per cent., of the 8,129 specimens had failed to survive to the eyed stage.

The loss in the eyed stage is estimated as follows: Firstly, the loss as shown by samples taken in the eyed stage alone is ascertained in the same manner as was the eyed-stage loss in the salmon redds. This time, however, the loss will be estimated on the basis of average loss per unit of development instead of per day. The total loss for portions of the eyed stage in the fourteen samples comprising 5,068 specimens taken in this stage is twenty-four. The eyed stage extends from the 26 per cent. to the 50 per cent. development stage—that is, for twenty-four units of development. The material taken from eyed redds represents 153 of such units. The loss for the whole eyed stage estimated from this material is $\frac{24}{5{,}068} \times \frac{14 \times 24}{153}$ —that is, seventy-three specimens. The eleven alevin samples, comprising 3,061 specimens, show a loss of 278 in the eyed stage. Thus 8,129 specimens show a total loss of 351, or 4·31 per cent., in the eyed stage.

It is necessary to consider what correction should be made for decomposition of ova to an irrecoverable stage. Unless dead ova contract fungus they remain in a recoverable state for a longer period than is required for incubation plus the portion of alevinage spent in the redds. It was ascertained under control conditions in a Westland stream that dead ova not attacked by fungus remain in a recoverable state in natural redds for at least a year. Dead ova buried in canisters in the bed of Slovens Creek were recoverable for at least thirty-five days after they contracted fungus. A perforated box containing seventy-seven live ova in stones was buried in the bed of Slovens Creek. All eggs were dead when the box was examined seventy-

one days later. All deaths had occurred when the ova were in the pre-eyed stage. The average time between deposition and death was approximately thirty days. The dead ova at the seventy-first day comprised fifty non-fungussed specimens, twenty sound fungussed specimens, and seven unsound fungussed ova. All except these seven ova could have been recovered intact from a natural redd. Thus, forty-one days after death, only 90·91 per cent. of the dead eggs would have been recoverable.

The average age when recovered of samples used for the ascertainment of the loss in the pre-eyed stage was eighty-nine days. Because of the decomposed state of much of the material, the point of development, which marked the peak of the loss in the pre-eyed stage, could not be very accurately determined. So far as could be judged, the peak occurred when ova had passed through about two-thirds of their pre-eyed development This point was reached in the case of the average sample at the thirty-

PLATE VI.—The stake indicates the position of a redd in Slovens Creek. The raised hand of the figure in the foreground marks the height reached by floodwaters in July, 1933.

seventh day. Thus in the average sample dead pre-eyed eggs had been dead for about fifty-two days.

It is sufficient for present purposes to ascertain whether or not dead eggs could have decomposed to an irrecoverable stage and, if so, whether any substantial correction should be made. It is clear that as only 90·91 per cent. were recovered of eggs dead, in the average case for forty-one days, less would be recovered after fifty-two days. Thus although 20·10 per cent. of the specimens recovered had failed to reach the eyed stage, a greater percentage of the eggs originally deposited died in the pre-eyed stage.

In the case of the loss in the eyed stage it is clear that the chances of any substantial error resulting from decomposition of dead specimens are much less because less time had elapsed between death and sampling.

In artificial redds in Slovens Creek at a mean temperature of 9·9° C., dead alevins 52 per cent. developed decomposed to an irrecoverable stage in six days; others 62 per cent. developed, in eleven days; others of 71 per

cent., in sixteen days. This mean temperature approximates to that in natural redds in this stream during alevin development. It should be noted in regard to the losses of alevins shown in Table 10 that generally the redds from which alevin samples were collected were redds in which pre-hatching losses were exceptionally high. From the earliest free-swimming alevins and the latest inhabitants of redds collected it appears that about 90 per cent. of development normally marks the termination of life in the redds.

In the winter of 1933 a flood occurred, which was exceptional in point of volume and abnormal as regards time of occurrence. Light wooden pegs which had been driven into the bed of Slovens Creek round a number of redds were not disturbed by the flood. These pegs were driven into the same depth as that at which eggs were buried in the redds. Although the surfaces of freshly finished redds in some cases resumed the level of the surrounding bed, it is certain that in no case were eggs in redds disturbed by this abnormal flood. Plate VI shows the extent of the rise of flood water on this occasion.

B. BROWN TROUT IN INCHBONNIE STREAMS.

Description of Streams.

In 1932, 1933, and 1934 the spawning of brown trout was studied in a number of streams on and in the immediate vicinity of the Inchbonnie Plain, in Westland. This plain is bounded on the east by the Alexander Range: on the south by the Teramakau River and by a range of hills extending from it to Lake Brunner which, over a mile and a half front, forms the western boundary of the plain. The northern side is flanked by Mount Te Kinga and, for a short distance, by the southern end of Lake Poerua, which lies between Mount Te Kinga and the Alexander Range. The length of the plain from eastern to western extremities is about six miles, the fall being from 400 ft. to 280 ft. above sea-level. In width the flat varies from two miles and a half to one mile and a half. The Government Meteorologist (in letter dated 29th March, 1934) advises that the mean annual rainfall at Greymouth on the Tasman Coast is 101·5 in., and at Otira, near the Main Divide, is 201·3 in. From records kept for seven months at Inchbonnie, which lies between these stations, he states that at a rough estimate the annual rainfall there is in the vicinity of 250 in.

The peaks rise very steeply from the flat to heights of from 4,000 ft. to 6,600 ft. They are heavily bush-clad to a height of over 3,000 ft. (Note.—the word "bush" has in New Zealand a meaning equivalent to that of the word "forest" overseas.) Formerly heavy bush extended on to the flat in belts up to half a mile wide along the top and sides, and up to a mile wide at the western end. Recent years have seen the clearing of most of the bush on the flat. To-day the Inchbonnie plain may be considered as consisting of two areas—a central one of light grassed land, and an area in which most of the material down to a depth of at least 15 ft. consists of water-worn stones and sand. Morgan(14) states that the plain is probably a former course of the Teremakau River. The other area comprises the marginal belts formerly carrying bush. This land is in a semi-cleared state, dead timber lying about on it and logs occurring in large numbers in the streams. There is a heavier coating of loam over this area. Along the northern side the subsoil consists of sandy material with clay in parts.

Rounded stones increase in proportion in the subsoil towards the western end of this side.

The courses of Harrys, School, Waterfall, Jims, Searles, and Pigeon Creeks and the Bruce Streams are shown in Fig. 7. Harrys and School Creeks enter Lake Poerua. The others, together with a series of spring

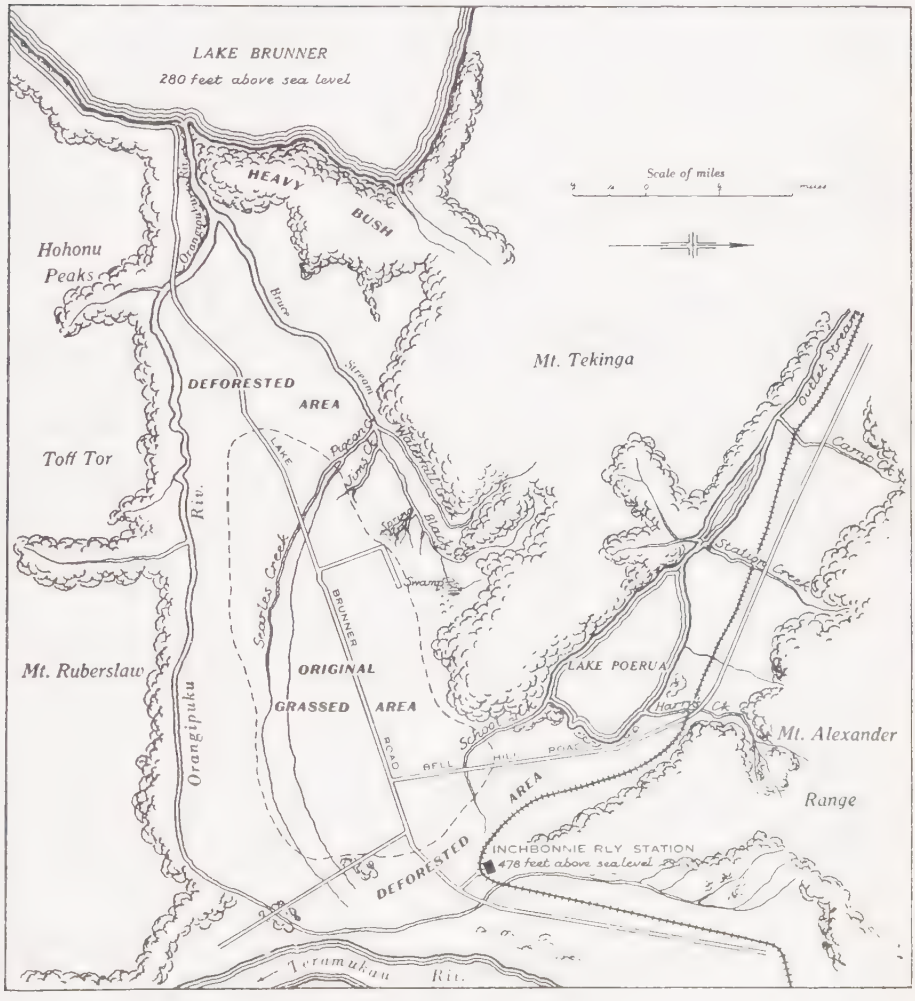

Fig. 7.—Streams in the Inchbonnie Area.

creeks which contribute much of the water, combine to form the left-hand branch of the Orangipuku River, locally known as the Bruce Stream. These streams are described in Table 11.

With the exception of Harrys Creek, which is a small but turbulent mountain stream, and Waterfall Creek, in which redds were sampled close to the hill where there was a considerable fall, the streams flowed through

TABLE 11.

Features.	Poerua System.		Bruce System.	
	School Creek.	Harrys Creek.	Black Creek.	Waterfall Creek.
Approximate length ..	1 mile.	¾ mile.	2 miles.	1 mile.
Approximate width ..	3 ft. to 8 ft.	5 ft. to 10 ft.	7 ft. to 15 ft.	4 ft. to 15 ft.
Approximate depth	3 in. to 30 in.	3 in. to 30 in.	3 in. to 36 in.	3 in. to 24 in.
Source	Spring.	Bush seepage off hills.	Bush seepage off hills and swamp drainage off flat.	Bush seepage off hills.
Range of temperature, degrees C., April to December, inclusive	8 to 12.	6 (?) to 15·5.	3 to 23.	1·25 to 17·5.
Nature of material comprising bed	Rapids: Rounded stones (greywacke) to 2½ in. with sand and clay; cementation considerable. Pools: Blue sand and logs.	Rapids: Flattened stones (mica-schist) to 18 in., with finer schist between; cementation very slight, yet bed firm. Pools: Finer mica-schist.	Rapids: Rounded stones (largely grey granite) to 2½ in. with granite grit and sand and a little brown bush detritus; cementation very slight. Pools: Grit, sand, and logs.	Rapids: Rounded stones (grey granite) to 18 in., with finer material of same nature; cementation negligible. Pools: Sand, logs, and bush detritus.
Quantity and nature of vegetation in pools	Moderate. Watercress (*Nasturtium officinale*) and less forget-me-not (*Myosotis palustris*).	Nil.	Meagre. Forget-me-not and rushes (*Juncus acutiflorus*).	Meagre. *Hydrocotyle tripartita*, *Elatina americana*, *Potamogeton Cheesemani*.
Diatomaceous growth ..	Meagre.	Meagre.	Moderate.	Negligible.
Nature of banks .. .	Grassed, rising to 2 ft.; undermined.	Vertical, rising to 6 ft.: in heavy bush on hillside.	Rising to 4 ft., in parts vertical, elsewhere grassed; scrub-covered.	Rising to 4 ft., generally grassed or scrub-covered; in parts vertical.
Floods—frequency and extent	Rare; mild.	Frequent; substantial.	Frequent; very substantial.	Frequent; substantial.
Flood-discoloration ..	Nil.	Brown (tea-colour).	Very brown.	Brown.
Movement of bottom material during floods	Negligible.	Moderate.	Slight.	Moderate.

Bruce System—*continued.*

Features.	Jims Creek.	Searles Creek.	Pigeon Creek.	Bruce Stream.
Approximate length	½ mile.	3 miles.	½ mile.	2 miles.
Approximate width	10 ft. to 14 ft.	3 ft. to 12 ft.	10 ft. to 14 ft.	16 ft. to 40 ft.
Approximate depth	6 in. to 60 in.	4 in. to 24 in.	4 in. to 42 in.	8 in. to 120 in.
Source	Springs.	Springs.	Springs.	Predominantly spring water.
Range of temperature, degrees C., April to December, inclusive	10 to 12·5.	3·5 to 17.	7 to 17.	9 to 13·5.
Nature of material comprising bed	Rapids: Rounded stones (greywacke) to 3½ in., with sand and a little finer matter; cementation slight. Pools: Blue sand.	Fairly even flow. More rapid portions. Occasional stones (greywacke) to 4½ in., with sand and much finer matter; cementation slight.	Fairly even flow. More rapid portions. Occasional stones (greywacke) to 4½ in., with sand and much finer matter; cementation slight.	(From entrance of Black Creek to entrance of Waterfall Creek). Rapids: Rounded stones (largely granite) to 2½ in., with grit and sand. Pools: Sand, logs; cementation negligible.
Quantity and nature of vegetation in pools	Very much. Watercress and less forget-me-not, milfoil (*Myriophyllum propinquum*), rush (*Elatina americana*).	Meagre. Milfoil, *Potamogeton*.	Much. Chiefly *Polygonum amphibium*, also watercress and milfoil.	Moderate. Watercress, rushes, *Polygonum*, *Hydrocotyle*, *Cardomine heterophylla*.
Diatomaceous growth	Moderate.	Meagre.	Moderate.	Meagre.
Nature of banks	Rising to 6 ft., grassed and scrub-covered; undermined.	Rising to 4 ft., scrub-covered.	Rising to 6 ft., scrub-covered.	Rising to 7 ft.; scrub-covered.
Floods—frequency and extent	Very rare; substantial.	Common; moderate.	Common; moderate.	Frequent; moderate.
Flood-discoloration	Negligible.	Negligible.	Negligible.	Slightly brown.
Movement of bottom material during floods	Negligible, but watercress breaks free.	Negligible.	Negligible, but forget-me-not breaks free.	Slight. Sand and sand-rooted plants are moved.

fairly flat country. None of the streams possesses a flood bed; in most parts of their courses water at mean level reaches from bank to bank. Apart from the two exceptions mentioned, the rate of flow in the streams is considerably less than that of the lower area of Winding Creek and is comparable with that of Slovens Creek above the fall. In the descriptions in Table 13 of material comprising the beds of streams, extremes only are described. In Harrys Creek redds were made in both the rapids and pools. In the other streams spawning was practically limited to the portions of the beds described as rapids. Temperature data are meagre in the case of Harrys Creek—it is probable that temperature falls below the point recorded.

Spawning-runs.

Scale-readings supplied by Mr. A. W. Parrott of samples of fish collected in the tributaries of the Bruce and of Lake Poerua show that these are almost essentially nursery streams holding in the summer very few fish of over two years of age. The spawning fish are drawn in the case of Harrys and School Creeks from Lake Poerua, and, in the case of the Bruce System streams, largely from Lake Brunner. In 1934 the spawning-run lasted for eight weeks in School Creek, at least twelve weeks in Harrys Creek, and for approximately five months in the streams of the Bruce System.

Generally in all streams mean water temperature was lowest in July, the month in which the peaks of the spawning-runs appeared to occur. In School Creek, where in 1934 substantially the whole run was trapped, of 99 fish handled, 28 were taken before July, 60 during July, and 11 after July. In Pigeon Creek in the same year a trap was installed after a few fish had entered and was maintained, with a few flood-time interruptions, until the end of the run. Of 314 fish captured, 42 were taken before July, 132 during July, and 140 thereafter.

Males in School Creek comprised 27 per cent. of total captures and in Pigeon Creek 34 per cent. Trout generally run most freely to spawn during floods and freshets. In many streams in the Inchbonnie area they run only during floods. Samples of trout ranging from four to thirty specimens netted in ten other streams in this area, as or shortly after flood-waters receded, showed in eight cases a numerical predominance of males—in one of the two smallest samples sexes were even; in the other females exceeded males. It is necessary to distinguish between a three or four to one excess of females over males in a complete spawning-run and the capture in spawning-areas of an excess of males. These observations are not conflicting. The proportions of sexes comprising the whole runs show that, since the efficiency of fertilization is very high, males must mate with successive females. A whole spawning-run comprises many minor runs of short duration. An excess of males was still present on spawning-areas sufficiently long after minor runs had taken place for females to have spawned and returned downstream. Such females as remained were nearly spent. Males, however, were not spent, although some were partially so. The facts show that during the spawning season far fewer males than females enter streams in the Inchbonnie area and that the males mate with successive females and tend to remain in the spawning-areas for this purpose. The efficiency of fertilization was found to be remarkably high wherever redds of brown trout were sampled at Inchbonnie.

The finding at Inchbonnie that spawning reaches a peak during the period of lowest stream temperatures, with the result that in most cases temperatures are rising during incubation and alevinage, is in accord with

observations in Slovens Creek. In each area, as has been very generally remarked by observers elsewhere, increased spawning-runs occurred during overcast weather or freshets—that is to say, brown trout approach spawning-areas most freely during conditions which cause temporary rises in water-temperatures and often increases in volume of water during the period of the year when temperatures are lowest.

It would have been very difficult, if not impossible, for fish to reach some of the spawning-areas in Harrys, Black, and Waterfall Creeks, except during floods. Generally these three streams both rise and fall again very sharply. In Black Creek, which also carries swamp water, the subsidence is slowest. In winter all three may be in heavy flood within two hours of the commencement of heavy rain. Harrys and Waterfall Creeks recede almost to fine-weather proportions within six hours of the cessation of rain; Black Creek may take forty-eight hours. It is not unusual to find in Black and Waterfall Creeks that the tops of redds project above the surface of the water during fine weather. Plate VII shows such a redd in Waterfall Creek. Ova are usually deposited at rather more than the average depth in redds of this type.

Plate VII.—A portion of Waterfall Creek, Inchbonnie, showing a redd made when the stream was in flood. When floodwater subsided the top of the redd projected above the surface.

Spawning activity is practically limited in these three streams to the duration of floods. Flood conditions seldom prevail for more than three or four days. In Black Creek a female, with very firm ovaries, was marked and liberated during a minor fresh. She was recaptured spent, save for three eggs (about the number normally retained), seventy-two hours later. She had not commenced to make a redd at the time of marking. In School Creek a female shed over two-thirds of her ova within twenty-one hours after entering the stream. Station or Dry Creek flows rapidly over a rough mica-schist bed to enter Lake Poerua. Of seven nearly spent brown trout examined in this stream four were very worn along the belly, the skin being punctured at the base of the pelvic fins. This is the only stream of those examined in which brown trout reach during spawning a physical condition

in any way comparable with that normally attained by quinnat salmon at or after spawning.

The very small size of many of the redds at Inchbonnie raised doubts as to whether trout normally shed all their eggs in one redd. In 1934 two pairs of marked fish were liberated at different times above a trap in School Creek in an area in which fish customarily spawn and from which all other spawners had been excluded. One female made three redds, the other one two redds. The greatest distance between any two redds made by a female was 350 yards. General observations suggest that where a stream-bed offers a large expanse of material of a suitable type for redds fish make large redds. Where there is a difficulty in finding an area of suitable type and extent a number of separate smaller redds will be made. As in Slovens Creek, trial redds were common in streams at Inchbonnie.

In marked contrast with the position in regard to redds of quinnat salmon in the Broken River system and of brown trout in Slovens Creek, there was, in the Inchbonnie streams, a dense massing of spawning-beds wherever the bottom material was suitable. As will be shown later, in a general discussion of causes of losses in redds, a proportion of the eggs deposited by the earlier spawners in streams in the Inchbonnie area are rooted out and killed through the spawning-operations of the later spawners. A limiting factor on productivity is thus operating. There is no record of any brown trout having been liberated in the Bruce or Poerua systems for over thirty years preceding 1934. The stock for many years past has been the product of natural spawning. If the areas studied are typical of those in the tributaries of lakes Brunner and Poerua generally, it is clear that, under existing conditions, no very considerable increase in the natural hatch can take place. A number of local residents who were interviewed were unanimously of opinion that there has in the last ten or fifteen years been a marked decrease both in the number and average size of fish in both the Bruce and Poerua systems. This view does not necessarily conflict with that of the writer as to the possibilities of an increase in the extent of the natural hatch. It is quite possible that the extent of the natural hatch is to-day much the same as before, although the extent of the deposition of ova may now be much less than it was formerly. The fact that spawning-runs are reputed to have shown a reduction, both in numbers and in average size of fish, may indicate that the spawning frequency per fish has dropped as a consequence of a reduction in average age.

Mr. James Shaffrey, of Inchbonnie, showed the writer short areas in two of the other spring creeks entering the Bruce in which trout spawned every year until eight or ten years ago. He stated that these two areas were typical of six such pieces of old spawning-water he could recollect in these two streams. The local residents, whose opinion in regard to reduction of stock has been given, were not referring to these streams. Watercress was first introduced into certain streams at Inchbonnie about eighteen years ago. At the time fish spawned in these streams they contained little of it. Short rapids, comprising largely stones of rounded greywacke, separated pools having beds of blue sand. To-day these streams carry an exceptionally prolific growth of watercress which almost completely mantles them, cloaking the beds, save when the streams have just been swept by floods. This luxuriant growth can be seen in Plate VIII. This growth has seriously retarded the rate of flow. Consequent on the reduction of current, vegetable detritus and fine material disturbed by the frequent passage of cattle across these streams have settled on and in time practically covered the stony portions of

the bed where formerly trout were able to spawn. In none of the different streams examined in which trout spawn have fish attempted to spawn in material such as now exists in these areas.

Material from Redds in the Inchbonnie Area.

No redds were marked in streams at Inchbonnie. Black Creek when in flood overflows its banks and steadily flowing water spreads overland to a breadth of 250 yards. Except when redds had been disturbed by the activities of subsequent spawners, they could be identified in Black Creek and elsewhere by superficial appearance, even when their contents had reached the alevin stage. This illustrates how little redds are disturbed by floods in these streams. It is not surprising that they are not disturbed when it is considered that they are constructed during floods.

Plate VIII.—A spring creek at Inchbonnie in which trout used to spawn. The watercress is growing in up to 6 ft. of water and rises 2 ft. above the surface.

Approximately fifteen thousand specimens of ova and alevins were obtained from fifty-six redds in eight streams sampled at Inchbonnie. Methods of collection and treatment of material employed were the same as elsewhere. A number of samples of less than fifty specimens each, generally taken inadvertently from contiguous redds, have been disregarded on account of their small size. A few larger samples have been disregarded where, in material taken from crowded spawning-areas, it was not possible to appropriate mixtures of dead specimens to their respective samples. With these exceptions all material collected is used here. Samples are considered to represent fairly the total contents of the redds from which they were taken. The material from Black Creek fairly represents spawning-areas as a whole in that stream. Material from other waters represents the more common type or types of spawning area in each stream.

Losses in Black Creek.

Material collected from Black Creek is analysed in Table 12.

Table 12.

Index No.	Total Sample.	Percentage Developed.	Total Dead.	Analysis of Dead.		
				Infertile.	Pre-eyed.	Eyed.
Pre-eyed—						
1	165	10	2	2	..	..
2	911	11	5	4	1	.
3	230	12	9	2	7	.
4	197	12	6	6	..	..
5	731	15	47	7	40	.
6	1,003	21	1	..	1	.
Eyed—						
7	213	27	0	..	..	..
8	301	27	8	..	8	.
9	393	27	47	..	47	.
10	282	28	3	3		.
11	445	30	18	..	17	1
12	276	35	9	..	9	..
13	1,486	36	47	..	47	..
14	217	37	11	..	11	..
15	62	49	6	..	3	3
16	178	50	11	..	11	.
			Alevins dead.			
Alevins—						
17	126	54	0			
18	107	56	0			
19	414	58	0			
20	64	59	0			
21	323	59	2			
22	85	61	0			
23	98	77	0			

Losses during incubation are not given in the case of alevin samples, for, in several instances, mixed samples of ova and alevins from different redds were taken together, and satisfactory appropriations of dead ova could not be made. It will be recollected that in Slovens Creek losses, as ova, in alevin samples had to be taken into account to overcome unrepresentative sampling which would otherwise have arisen. Here no such difficulty arose, as conditions in different spawning-areas were fairly uniform.

The 857 specimens in the four samples suitable for the purpose (Nos. 1, 4, 7, and 10) show a non-fertilization loss of 11, or 1·28 per cent. The loss before eyeing, which includes the non-fertilization loss, is determined from the 3,853 which comprise the ten eyed samples. Of these ova, 156, or 4·04 per cent., did not survive to the eyed stage. The loss in the eyed stage, estimated as in the case of the salmon material but on the basis of loss per degree of development instead of per diem, is as follows: $\frac{4}{3,853} \times \frac{24 \times 10}{86} \times \frac{100}{1}$ = 0·29 per cent. Thus losses to hatching total 4·33 per cent.

It is considered that no correction need be made to this figure for decomposition of ova. The redds sampled included those made at various times during the spawning-season. The peak of spawning activity occurred near the middle of July. Ova deposited on the 15th July eyed at about the 24th August and hatched at the end of September. Thus the eyed period extended for about thirty-seven days. About forty days elapsed from the middle of the pre-eyed period until the middle of the eyed period.

Development is more rapid in Black Creek than in Slovens Creek. In the latter stream under experimental conditions ova were recoverable for at least thirty-five days after they were infected with *Saprolegnia*. In Slovens Creek a proportion of the dead eggs taken with eyed samples were too decomposed for appropriation with certainty to the pre-eyed or eyed categories. With such samples fragments of long dead ova were also recovered. In Black Creek there were taken neither egg-fragments nor ova so decomposed that they could not easily be classified. Decomposition of dead ova, considered in relation to the rate of development of live ova, is much slower in Black Creek than in Slovens Creek.

A very low death-rate in the alevin stage is indicated.

Losses in Other Inchbonnie Streams.

Material collected from other streams in the Inchbonnie area is analysed in Table 13.

Table 13.

Stream and Index No.	Total Sample.	Percentage developed.	Total Dead per Centum	Analysis of Dead (Percentages).				
				Decomposed.	Infertile.	Pre-eyed.	Eyed.	Alevin.
Harrys Creek—								
1 (eyed) ..	540	38	15·17	..	4·25	10·74	0·18	..
2 ,, ..	352	40	0·85	..	0·85	..	..	..
3 ,, ..	638	46	0·89	..	..	6·89	..	..
4 ,, ..	302	50	9·92	..	2·31	7·28	0·33	..
School Creek—								
1 (pre-eyed) ..	330	Under 10	1·21	..	0·30	0·91	..	
2 ,, ..	216	19	0·46	..	..	0·46	..	..
3 ,, ..	167	21	0·59	..	..	0·59	..	..
4 ,, ..	212	22	2·83	..	..	2·83	..	..
5 ,, ..	79	25	3·94	..	..	3·94	..	..
6 (eyed) ..	357	39	14·28	..	..	14·28	..	..
7 ,, ..	261	48	16·47	..	..	11·49	4·98	
8 ,, ..	247	49	5·66	..	..	3·64	2·02	..
9 (alevin) ..	153	55	86·92	..	..	20·26	66·01	0·65
Waterfall Creek—								
1 (pre-eyed) ..	183	Under 10	3·27	..	3·27	..	..	..
2 ,, ..	111	16	13·51	..	3·60	9·91	..	
3 (eyed) ..	266	29	2·25	..	..	2·25	..	..
4 (alevin) ..	116	58	5·16	..	..	5·16	..	..
Jims Creek—								
1 (pre-eyed) ..	150	23	0·66	..	..	0·66	..	..
2 (eyed) ..	310	27	0·00	..	..	..	..	..
3 ,, ..	54	39	1·85	..	..	1·85	..	..
4 ,, ..	118	41	0·85	..	0·85	..	..	..
5 ,, ..	494	44	3·64	..	..	3·24	0·40	..
Searles Creek—								
1 (pre-eyed) ..	63	Under 10	0·00	..	..	..	..	
2 ,, ..	61	Under 10	1·66	..	1·66	..	..	
Pigeon Creek—								
1 (pre-eyed) ..	76	23	5·26	..	..	5·26	..	..
2 ,, ..	51	26	94·12	..	..	94·12	..	
3 (alevin) ..	135	78	85·67	..	..	65·18	20·49	..
Bruce Stream—								
1 (pre-eyed) ..	94	Under 10	1·00	..	..	1·06		..
2 ,, ..	69	13	0·00	..	..	..	..	
3 ,, ..	136	21	5·14	..	..	5·14	..	
4 (eyed) ..	198	38	3·02	..	1·51	1·51	..	..
5 (alevin) ..	121	69	1·70	1·70	..	..	..	
6 ,, ..	119	81	4·20	..	3·36	0·84	..	

There is not from any one of these streams sufficient material to enable losses throughout life in the redds to be ascertained. The collection of

material for such a purpose was not attempted. These samples were collected with a view to ascertaining reactions of ova and alevins to different environments. The disparity in losses in redds in different portions of School and Pigeon Creeks indicates how marked a difference in mortality rates may occur even in streams of very short courses. Losses in particular cases will be discussed in a later section of this paper.

Taken as a whole this material, representing a great diversity of environmental conditions, shows that the emergences of alevins indicated in Slovens and Black Creeks are not in any way exceptional.

The samples obtained from these seven streams are not representative of the relative intensity of the spawning in these streams. Losses, the extent of which has not been measured, are caused by the superimposition of redd upon redd in some and possibly all these streams.

C. BROWN TROUT IN THE SELWYN RIVER.

Description of Stream.

The Selwyn River rises in the eastern foothills of the Southern Alps and pursues a course of about fifty-six miles, largely across the Canterbury Plains, to enter Lake Ellesmere. There is permanent water in the foothills and again for fourteen miles or so before the stream enters the lake. Water seeps below the shingle in the intervening portion of bed. A connection of surface water between the upper and lower reaches is maintained during and for a short time following floods. The winter and spring of 1934 were rather exceptional in that a moderate flow of surface water over the middle portion occurred much more regularly than in other years.

Conditions were studied in spawning-areas of brown trout between the Selwyn Huts, about two miles from the mouth, and the bridge on the Main South Road, about eighteen miles from the mouth. Within these limits much of the large run of trout from Lake Ellesmere usually spawns. A portion of the run is trapped in the lower part of this area by the North Canterbury Acclimatization Society to obtain ova for hatchery purposes. In all, forty-three samples, of suitable size and age for determinations of losses, were taken from redds. Of these, nine were taken from below Coes Ford, fourteen from the half-mile of water immediately above Coes Ford, two from the mouth of a small creek entering from the right shortly above the ford, ten in the vicinity of Chamberlains Ford, and eight from the mile of stream-bed immediately below the Main South Road. All except the last eight samples were taken from the lower area of permanent water. Three samples were collected in 1933; the remaining forty in 1934.

Where redds were examined in the lower area of permanent water the stream varies in width from about 15 ft. to 45 ft. Generally the bed is of shingle—largely rounded greywacke—admixed with finer matter. Clay occurs in the mixture which is loosely cemented. The bed carries a moderate growth of diatomaceous matter. The material in the dirtier portions of the bed of the Selwyn is comparable with that in the cleaner portions of Slovens Creek. Narrow marginal shingle banks frequently occur. Elsewhere banks are grassed or willow-clad or again are eroded and rise vertically to as much as 6 ft. Marginal and bed-rooted vegetation is extremely limited in extent. The larger vegetation on the banks consists in parts of willow trees, gorse, and broom. The deposit on the banks and the nature of the banks and stream-bed indicate that, although severe floods have swept the stream on occasions in the past, floods causing substantial modifications of the stream-bed are infrequent occurrences. It is probable that not infrequently the annual redd-making activities of fish alter the bed to a much greater extent than annual floods do. Mr. J. Digby (*vide* letter, Appendix E)

states that the upper and lower areas of permanent water had not been connected by flood-water during the preceding three winters.

In the upper portion of the area sampled, towards the Main South Road, where there is not a permanent flow over the surface, there is a wide shingle flood-bed, where gorse and broom flourish on shingle and sand on the higher levels.

Material was collected during occasional visits paid to the stream from the middle of June until the end of September. Temperature data are few. They consist of seven readings taken in 1934. These show a maximum of 11°, a minimum of 8·5°, and a mean of 9·9° C.

Spawning-areas.

In the region of permanent water there was, in suitable places, a dense massing of redds almost comparable with that observed in portions of the Bruce system. While it was apparent that the bottom had been disturbed over considerable areas by spawning activity, individual redds frequently lacked definition. In such places only the more recent redds were distinguishable, and many samples were obtained by digging at random in disturbed areas of stream bed. While conditions suggested the probability of losses being caused by the superimposition of redds upon earlier redds, in the limited time available it was not possible to ascertain if such losses take place.

In the shorter area of impermanent water intensity of spawning was much lighter, probably because of the relatively limited duration of the accessibility of this area to fish. Redds there were well defined, and there was nothing to indicate a possibility of superimposition taking place. It is interesting to note that weather-conditions may bring about a variation from year to year in the total extent available of stream-bed suitable for spawning. If losses occur through superimposition in the lower waters, this fact might cause differences in the extent of the natural hatch. It was obvious at the time of examination that there had been a very marked reduction in flow since the redds had been made. The stream was reduced to a chain of pools connected in some places by flowing surface water and in others only by water seeping beneath the surface. A number of redds were still covered by water. Portions of the mounds of others projected above the surface of the water, just as they frequently do in Black and Waterfall Creeks. Less commonly redds were found in the course where water had ceased to flow on the surface. In such cases redds might be as much as 50 yards distant from water flowing on the surface. One such redd is shown in Plate IX.

Redds in this last condition were of particular interest. Two such redds were examined under most favourable conditions. A study of the distribution of ova in them confirmed deductions from observations made elsewhere under less favourable conditions. Ova in them were almost entirely confined to definite egg-pockets in which numbers of the ova were in contact with one another. Professor E. Percival, of Christchurch, who was with the writer when these redds were examined, kindly returned later and photographed several similar redds. One of these contained, in a total area of disturbed bed of approximately 12 ft. by 2½ ft., four distinct egg-pockets. Each pocket was approximately 5 in. by 5 in. in area. The four pockets yielded a total of 1,425 ova. Generally redds contained less than four pockets. Plate X shows the massing of ova in a typical egg-pocket just as it was uncovered. No other ova were present in the vicinity of this pocket, which represented only a small proportion of the total area dug by the fish.

Material collected from redds in the Selwyn River is analysed in Table 14. Redds sampled in the area of impermanent water are prefixed by an asterisk in the table. In the two redds the writer examined in apparently dry portions of stream-bed (Nos. 8 and 23 in Table 14) the material, with the exception

[*Photo by E. Percival.*

PLATE IX.—A "dry" redd, which contained healthy ova, in the area of impermanent water in the Selwyn River. Note the larger stones at the upstream (spade) end of the redd.

[*Photo by G. Helson.*

PLATE X.—Live ova in egg-pocket in opened trout-redd in Selwyn River. Water had not passed over the surface of this redd for five weeks.

of the immediate surface stones, was damp. In each case the water-table was approximately 6 in. below the ova. The material in these redds was exceptionally clean. Professor Percival, who examined several similar redds a fortnight later, states that in a fairly typical one, over which surface water had not passed for five weeks, 83 per cent. of the ova was alive. It is known that at irregular intervals thereafter there was an unbroken flow of surface water from a point at least as far upstream as the Main South Road and down to the mouth. There is therefore no reason to believe that alevins would not have been able to escape from these redds.

So far as could be judged, without making a thorough survey, the representation in Table 14 of redds from this impermanent water region is too heavy. It will be noted that these samples show a heavier than average loss.

TABLE 14.

Index No.	Total Sample.	Age in Days.	Total Dead.	Analysis of Dead.		
				Infertile.	Exosmosis.	
					Non-fungussed.	Fungussed.
1 (pre-eyed) ..	132	Under 10	2	2	..	..
2 ,, ..	119	Under 10	1	1	..	..
*3 ,, ..	122	Under 10	1	1	..	..
4 ,, ..	228	Under 10	0	..	..	..
5 ,, ..	629	Under 10	10	9	1	..
*6 ,, ..	428	14	3	3	..	..
7 ,, ..	543	15	11	10	1	..
*8 ,, ..	591	17	2	2	..	..
9 ,, ..	703	18	12	11	1	..
*10 ,, ..	144	18	1	1	..	..
*11 ,, ..	652	19	0	..	..	..
12 ,, ..	347	20	2	..	2	..
13 ,, ..	422	20	12	8	4	..
14 ,, ..	308	20	6	6	..	..
15 ,, ..	395	20	10	7	3	..
16 ,, ..	378	26	2	2	..	..
17 ,, ..	104	27	0	..	..	..
18 ,, ..	348	27	7	6	1	..
19 ,, ..	432	28	3	..	2	1
20 (eyed)	863	29	15	3	3	9
*21 ,, ...	707	29	74	23	18	33
22 ,, ...	318	30	10	5	5	..
*23 ,, ...	719	30	65	1	..	64
24 ,, ...	582	30	41	9	2	30
25 ,, ...	661	31	4	..	2	2
26 ,, ...	112	32	1	1	..	..
27 ,, ...	371	33	6	3	2	1
28 ,, ...	1,275	33	12	6	6	..
29 ,, ...	229	34	7	2	1	4
30 ,, ...	757	34	4	3	..	1
31 ,, ...	424	38	6	..	4	2
*32 ,, ...	139	39	2	2	..	..
*33 ,, ...	494	44	1	..	1	..
34 ,, ...	823	47	2	..	..	2
				Alevin loss only.		
35 (alevin) ..	368	51		0		
36 ,, ..	176	56		0		
37 ,, ..	397	59		0		
38 ,, ..	156	61		4		
39 ,, ..	179	69		4		
40 ,, ..	119	70		0		
41 ,, ..	135	78		0		
42 ,, ..	83	82		0		
43 ,, ..	180	96		4		

It will be noticed that there is a progressive decrease in the number of samples comprising the three main divisions. This results from the lack of definition of the older redds in crowded spawning-areas. Naturally the contours of the more recently finished redds were best preserved. Thus older redds were harder to find. The relatively small size of the alevin samples is partly attributable to the same cause. When recently finished redds are being dug the material disturbed by the fish may be distinguished more easily from the undisturbed stream-bed. The older the redds are, however, the more have they tended to resume the character of the surrounding bed, and the greater, therefore, is the difficulty of exhausting an egg-pocket or finding further pockets should the sample from the first prove insufficient.

Temperature data showed a mean of 9·9° C. In Table 14 percentages of development have been converted into days as at 10° C., temperature being taken as at the nearest degree for this purpose.

The sample of alevins from Redd 43 was further developed than was any other sample taken in the Selwyn or elsewhere. This sample was 96 per cent. developed. Yolk was not visible on the ventral surfaces of these larvæ. Free-swimming alevins were seen among stones on the surface of this redd. These were not captured. It is possible, therefore, that some alevins had emerged from this redd. It is doubtful if this sample is properly included, as dead recovered may be representative of a greater total number of alevins than was recovered. Reverting to the question of the point of development normally attained before emergence from redds in the Selwyn, two free-swimming alevins of less than 80 per cent. developed were taken with forty fry at Coes Ford. The probability is that these two specimens had emerged earlier than is usual, while the alevins in Redd 43 would have emerged later than usual. It is probable that alevins generally emerge in the Selwyn before they are 95 per cent. developed.

Dead ova recovered with alevin samples are not shown in Table 14. As in Black Creek, there were recovered, with alevin samples, ova from contiguous redds; and dead ova could not always be apportioned with certainty between such alevin samples and ova samples. No dead eyed ova were recovered. No dead ova in samples of ova were so decomposed that they could not be appropriated with certainty to their proper category. A special analysis has been made of the dead ova. Firstly, infertile ova, in which exosmosis had not taken place, are shown separately; secondly, dead ova, which had suffered exosmosis, have been divided according as they had or had not become infected with *Saprolegnia* to an extent visible to the naked eye. This analysis is instructive in that it shows that in a stream such as the Selwyn, where incubation is comparatively rapid, infertile eggs are slow to lose their osmotic stability. Thus the time at which infertile eggs become available to the decomposition agent *Saprolegnia* is frequently delayed until the fertile eggs are approaching hatching-point. Further, the analysis indicates that there is a considerable gap between the time when, by suffering exosmosis, any eggs become available to this decomposition agent, and the time when such ova become visibly infected. Exosmosis of dead ova is recorded as occurring before the tenth day, yet *Saprolegnia* was not noted until the twenty-eighth day. It will be seen that decomposition to an irrecoverable stage of any dead ova in either pre-eyed or eyed samples could not have occurred, for, at the most, ova were infected for only nineteen days. The losses shown by pre-eyed samples are very light and comprise largely infertile eggs. Apart from their use for determining the percentage of fertility, these samples have a value in that they show losses for portions of pre-eyed development which are not inconsistent with the total loss for that period as estimated from eyed samples.

Attention is directed to the relatively heavy losses in Redds 21 and 23 and to the fact that all dead ova, other than infertile ones, in Redd 23 were infected with *Saprolegnia*. Further reference will be made to these redds at a later stage of this paper.

A total of 3,457 ova was obtained from thirteen redds in which no specimens had suffered exosmosis. Of these ova, twenty-one, or 0·60 per cent., had not been fertilized.

The 8,474 ova recovered which had completed their pre-eyed development showed a loss of 250 specimens, or 2·95 per cent., before eyeing. This figure includes losses through non-fertilization. As no loss was recorded in the eyed stage a hatching of about 97 per cent. is indicated. The small losses of alevins recorded suggest that most of the alevins could be expected to survive life in the redds.

The dense massing of redds in some portions of the Selwyn indicated the possibility of earlier deposited eggs being rooted out by the activities of late spawners. Any such loss would be additional to that shown by present material.

D. SUNDRY BROWN TROUT REDDS.

Besides the larger collections of samples from redds of brown trout, already dealt with, a few redds were sampled in Winding Creek, in the Main Drain, and in the Avon River. In no case were the samples sufficient to enable losses to be traced throughout life in the redds. As most of the samples had not developed sufficiently to show the effects of adverse environments, no lengthy description of these streams is needed here.

Winding Creek has already been described. The other two streams pursue courses of varying lengths across the Canterbury Plains towards the Pacific Coast.

Main Drain: Comparable in volume with Slovens Creek; confined to a straight channel in which water is generally less than 12 in. deep; marginal vegetation occurs; bottom generally of rounded stones to 2 in. loosely cemented in fine material—largely clay; degree of cementation a little less than in Slovens Creek; good growth of diatoms; spawning fish enter from tidal water.

Avon River: Spring creek of short course; bottom consists largely of very fine matter growing much *Elodea canadensis*; short, very dirty rapids occur infrequently; in rapids degree of cementation far the greatest yet noted; permanent population of small fish.

Material from redds in these streams, sufficiently developed for satisfactory determinations, is given in Table 15.

TABLE 15.

Index No.	Total Sample.	Percentage developed.	Total Dead, per Centum.	Analysis of Dead (Percentages).	
				Infertile.	Pre-eyed.
Winding Creek—					
1	729	11	2·31	2·31	..
2	689	13	5·51	2·11	3·40
3	559	14	2·68	1·25	1·43
Main Drain—					
1	453	11	0·44	0·44	..
2	115	13	2·98	0·85	2·13
3	470	15	0·00	..	..
4	911	23	1·20	0·98	0·22
Avon River—					
1	274	Under 10	5·47	..	5·47
2	286	11	1·74	1·74	..

SECTION IV. – RAINBOW TROUT IN WINDING CREEK.

Winding Creek contains throughout the year a population of rainbow trout. Fish observed ranged from ½ lb. to 7 lb. Spawning extended in 1933 from the first week in August to the second week in October.

The nature of the bottom material chosen for sites for redds by this species was the same as that chosen by brown trout. Rainbow sometimes chose sites more exposed to view and frequented the redds more in the daytime than did brown trout. The redds were in structure like those of brown trout. The eggs were lodged in equally well-defined egg-pockets at a depth of about 8 in. below the surface of the bed. Only seven redds were marked. Five samples of ova were obtained from four of these, which were opened. In one case samples were taken at different dates from different pockets in the same redd.

Bowers(3) gives forty-two to forty-five days as the time that rainbow trout eggs take to hatch at 50° F. He accepts a variation of five days in the duration of incubation per degree F. difference in temperature. In order to ascertain the age of the samples obtained it has been necessary to assume that after completion of any part of incubation the relationship of embryo length to ovum diameter is the same, under like conditions, in the eggs of both rainbow and brown trout. The mean water-temperature was 9° C. The calculated total duration of the incubation period was fifty-one days. Details of samples collected are given in Table 16.

TABLE 16.

Index No.	Total Sample.	Age, in Days.	Total Dead, per Centum.	Analysis of Dead (Percentages).	
				Infertile.	Pre-eyed.
1	330	11	0·30	0·30	..
2	392	14	0·25	0·25	..
3A	1,549	17	0·51	0·38	0·13
3B	553	25	0·18	0·18	..
4	868	36	2·73	0·57	2·16

Four days elapsed between the collection of the two samples from Redd 3. The calculated difference in the age of the two samples was eight days. This does not indicate an error of four days in the calculation. The two samples were taken from different pockets which had probably been made at different times. The material shows an exceptionally high efficiency of fertilization and indicates a low subsequent mortality.

SECTION V.—LIFE IN THE REDDS.

It has been shown that the redds, made by the three species under consideration, are essentially similar in nature. In extent the redds of quinnat salmon are greatest and ova are deposited at a greater depth in them than in redds of either species of trout. In this and the immediately succeeding section general statements may be read as applicable to the redds of all three species unless the contrary is indicated by the context

Initial Differences in Redds.

Ova are deposited in a great variety of environments. Not only do conditions vary from stream to stream, but they vary in different portions of any one stream. Even in the same area in one stream the deposition of ova in redds at different times may result in ova being subjected to different conditions. Variations in mean water-temperature to which ova were subjected, resulting from deposition either in different streams or in different areas in one stream or at different times in one stream, cause marked differences in the duration of life in the redds. Sometimes ova are subjected to widely fluctuating temperatures: other times to a relatively constant temperature.

Redds of any one species vary in size and shape, and occasionally in depth of ova-stratum. The number of egg-pockets per redd and of ova per pocket varies. The material comprising redds is not uniform in composition. Over some redds the depth of water and rate of flow are greater than over others. The permeability of redds can scarcely be uniform. The distribution of ova in any one redd is such that the same amount of water, and therefore of oxygen, cannot be available to each egg.

The newly made redd is an area of relatively clean material in a larger area of normal stream-bed. Surface diatomaceous growth is lacking. Such diatoms as were previously attached to stones on the surface have been buried and do not survive long. The organisms which previously flourished among the diatom-covered stones have been swept away along with the fine material as the redd was being made. Progressively as the redd ages it tends to resume the character of the surrounding bed. Fine material is deposited in it, diatom regeneration occurs, and repopulation by aquatic beasts of the surface zone takes place. While ova or alevins remain in the redds, it is unusual for the silt to penetrate as far as the egg-pockets. Silt does not sink down to the egg-stratum and build up from there to the surface. Where silting occurs it is usual to find a silt "crust" formed in the surface material. This overlies a stratum of cleaner material. Later this crust may extend downwards, eventually meeting the undisturbed bed underlying the redd. The rate at which redds tended, through silting, to resume the character of the surrounding bed varied greatly. While there is always a tendency for the surface of the redd to flatten, in many cases alevins emerge before this happens. In Winding and Slovens Creeks, so rapid was the regeneration of diatoms, that redds were no longer distinguishable as such, by colour of surface material alone, six weeks after they were made. Repopulation by aquatic animals was much slower and appeared to increase throughout both incubation and alevinage in such high temperature

streams as Winding Creek and during incubation and the early part of alevinage in colder streams like Slovens Creek. The quantative determination of the number of beasts per unit volume of material at successive levels of a vertical section of a redd was not attempted. It was abundantly clear, however, that virtually the whole animal population in any stream-bed was limited to the 2 in. or 3 in. of immediate surface material. With the exception of occasional worms, the ova-strata of redds were free of fauna.

Alevins of brown trout or quinnat salmon, on hatching, do not immediately commence their ascent from the ova-stratum to the surface. For the first half at least of alevinage they remain in the ova-stratum. They do not reach the "crust" of silt until at least the 80-per-cent.-development stage in the case of brown trout, or the 85-per-cent. stage in the case of salmon, is arrived at. Thus by the time they reach the environment containing a variety of other animals they are no longer puny larvæ.

It is commonplace that ova and alevins must have a sufficient supply of oxygenated water if they are to live. Any lessening of the permeability of redds through silting must lessen the oxygen-supply. Thus, other conditions being equal, very generally the amount of oxygen reaching eggs and alevins in redds will become progressively less as the redds age: the lower the temperature is the slower will development be, and thus the longer will be the period over which oxygen-supply can be reduced by silting. Where the rate of silting is uniform, less water will penetrate to ova or alevins of any particular percentage of development in redds in streams of low temperature than in streams of high temperature. Little precise knowledge of the oxygen-requirements of ova and alevins of Salmonidæ is available. Wood(22) has determined the oxygen-requirements of alevins of brown trout at different temperature. His determinations cover the period from hatching until about the 85-per-cent.-development stage. They were made at temperatures of 3°, 7°, and 12° C. His data show that the rate of respiration at any temperature remains fairly uniform for some time after hatching, and then decreases markedly by the time external yolk is absorbed. It is interesting to note that in natural redds this decrease in oxygen-requirement will take place as the alevins are ascending from the relatively clean ova-stratum and entering the overlying silt "crust." Wood's data show that the oxygen-requirement per unit of time is at 3° C. about one-third and at 7° about one-half what it is at 12° (data on this point are re-presented in Appendix D). It is therefore clear that in natural redds ova could be suffocated at high temperatures when, other conditions being equal, they could live at low temperatures. Thus to offset the disadvantage that low temperature brings about by increasing the time in which silting can occur (and thus oxygen-supply can be reduced), there is a compensating advantage through oxygen-requirement being less.

SECTION VI.—THE CAUSES OF LOSSES.

A. LOSSES OUTSIDE THE REDDS.

Before proceeding to an examination of losses taking place actually in the redds, it is necessary to consider the following questions :—

(1) Do all fish in which eggs mature manage to spawn ?

(2) Do the fish discharge all ova which mature ?

(3) Do the eggs discharged lodge in the redds ?

These questions are really outside the scope of the work undertaken, consequently conclusive treatment is not possible.

1. Losses through Fish not Spawning.

Observations did not show that any quinnat salmon succumbed from natural causes, in the spawning-areas, before extruding their ova. No increase was noticed in the Broken River area during the salmon-spawning season in the numbers of black-backed gulls (*Larus dominicanus*), black shags (*Phalacrocorax carbosteadi*), or white-throated shags (*P. brevirostris*). Gulls were observed eating dead spent quinnat. There was nothing to indicate that they, or shags, attacked live adult quinnat.

Salmon were legitimately fished for, on the spawning-redds, by anglers. They were also poached in Broken River and Winding Creek in 1932 and in Broken River and Slovens Creek in 1933.

Extensive poaching of spawning brown trout at Inchbonnie took place for many years, but it moderated considerably in intensity from 1931 onwards. Apart from one instance shortly to be mentioned, no loss of brown trout from natural causes was noted to occur in any of the streams in which redds of brown trout were examined. Only in Slovens Creek and in the streams at Inchbonnie were observations really intensive enough to show whether or not natural losses of brown trout normally occur during spawning.

Two possible instances of natural loss of ova of spawning brown trout before deposition were noticed at Inchbonnie. In one case the parent fish succumbed. Eels (*Anguilla dieffenbachii*) of up to at least 6½ lb. were noticed in streams at Inchbonnie when trout were spawning. One of three live trout captured at night on 12th July, 1933, was totally spent. It had, on either flank, a roughly triangular abrasion extending up for 2½ in. from a base which centred round the female's vent. In shape the abrasion was such as might be expected to occur if an eel were to seize the fish in such a position. On the same date a totally spent dead female trout was recovered. It had a similarly shaped marking in exactly the same position. The abrasion was, in this case, infected with *Saprolegnia*. Infection had preceded death.

A few very large eels enter the trout-traps placed each winter in the Selwyn River. Mr. J. Digby (see letter, Appendix E) has for many year stripped trout there. He stated that frequently ripe female fish have to b held over night in a pen until sufficient males are caught. On the only occasion that he left two large eels (about 15 lb.) in a pen over night with ripe female trout, all the 30-odd trout were spent the following morning. He has never known ripe females, separately penned up, to lose their ova.

2. The Completeness of Spawning.

Practically all the ova which mature in quinnat salmon or brown trout are discharged. Figures, already given in the case of salmon, show an average retention of eight ova per female. Fourteen spent female brown trout trapped at Inchbonnie as they ran downstream within a few days of completion of spawning had, in the average case, retained 6·7 ova each.

3. Lodgment of Ova in Redds.

Not all ova extruded by fish lodge in the redds. One brown trout and four rainbow trout captured in Broken River on 15th and 16th April, 1933, had ova of quinnat salmon in their guts. These five trout were captured as a result of two days' fishing by two skilled anglers. They saw altogether thirteen trout in three miles of water. The number of eggs and egg remains, per gut, varied from one to thirty-eight. In point of number the ova were not significant beside the total number of animals, aquatic and terrestial, present in the stomachs. It is clear that no fish had fed exclusively on ova for any length of time. These were either ova shed by salmon on their way upstream or ova which had failed to lodge when shed over redds. If they were ova which failed to lodge, the nature of the gut contents suggests that the escapage was not sufficient to provide trout with an exclusive diet of ova for any length of time.

At Inchbonnie eggs of brown trout were recovered from the stomachs of brown trout. In certain cases (to be discussed later) these were ova from earlier redds which had been disturbed by the superimposition of new redds upon the older ones. In other cases it is not clear whether such ova resulted from initial non-lodgment or from disturbance upon superimposition occurring.

Trout ova, at the moment of extrusion, are very soft, translucent bodies, roughly spherical in shape. They have a specific gravity of 1·25. On being immersed in water they absorb water and increase their former weight by approximately 22 per cent. This increase in weight is accompanied by a considerable hardening and also by a lessening in translucency. The specific gravity drops to 1·08. When first immersed the eggs are sticky, but later the adhesive quality is lost. Eggs become also more spherical than before. The rate at which these changes are brought about increases as water-temperature increases. The shortest time required for ova to lose their adhesive quality at the temperatures prevailing at Inchbonnie during the spawning-season was about ten minutes. Ova of quinnat salmon undergo like changes when first immersed in water, but the extent of their increase in weight and loss in specific gravity was not determined.

In Black Creek it was found that only 40 per cent. of a sample of fifty "green" eggs of brown trout drifted as far as 5 ft. in a current of 1·6 ft. per second. This was over an undisturbed piece of stream-bed, comprising stones of up to 1½ in., situated between two spawning-areas, over which a slower current flowed. Nine of a sample of fifty "green" eggs released in one of these two latter areas, where the current was 0·8 ft. per second, drifted as far as 5 ft. The bed here comprised material similar to that in the former area.

A spawning fish, however, does not shed its eggs at random in the stream-bed, but prepares a special place for them. The nature of the current passing through the pits of partially made redds of quinnat salmon and brown trout was determined by the introduction into them of potassium

permanganate crystals. It was found that in the deep basin-shaped depressions of the partially made redds there was practically dead water. Such current as there was arose in the following manner: The relatively rapid water passing over the top of the basin struck the mound of material excavated in the forming of the basin and, in the main, passed up and downstream over it. Some little of the water followed down the back wall of the basin, upstream along the "floor" of it, and then up the forward wall, to mingle again with the surface water. There is thus a steady downstream flow passing over the top of the basin and a very slow upstream flow along the bottom of the basin. A longitudinal section of a trout-redd at the stage at which ovi-position occurs is shown in Fig. 8.

Observations on natural redds indicated that ova are shed when currents of the nature just described are passing over and through the basins of partially made redds. When digging out redds which contained odd stones of more than average size it was noticed that ova, when originally deposited, had tended to lie most densely under the upstream ends of such stones. Such a distribution is indicative not of a current passing downstream through the basin, but upstream.

All the ova were removed from two typical redds of brown trout, one in Black Creek and one in School Creek. The materials were levelled out and

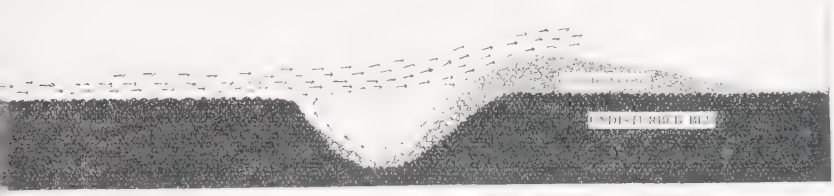

FIG. 8.—Longitudinal section of trout-redd, showing nature of currents at time of oviposition.

artificial redds were constructed, work ceasing at a point when it was considered that they fairly represented natural redds at the time of oviposition. A net was set below each redd. In one case 500, and in the other 100, "green" eggs were placed in the redds. They were introduced by being gently expressed from a syringe, the mouth of which was held 1 in. below the flow of surface water and approximately 7 in. above the bottom of the pit. The ova were then covered by material, which was slowly shovelled down in small quantities from the upstream wall of the depression. The deposition, and covering of the ova, were carried out, in the case of the sample of 500, with an escapage of 3 per cent. from the redd, and in the case of the sample of 100 without any loss. The deposition of the larger sample occupied a considerable time, and the earliest deposited ova had partly lost their adhesiveness before covering commenced. To this fact the escapage is attributed. It is not known for certain how long it takes a fish to extrude the ova destined for any one pocket or to cover the ova when extruded. The experiments suggest that fish could extrude and cover ova with very little, if any, loss. It is considered that eggs must normally be shed and covered before the adhesive quality is lost. It is difficult otherwise to see how ova could remain densely massed in an egg-pocket during the covering process.

In Winding Creek a pair of rainbow trout, a female of about 19 in. and a male of about 12 in., were observed on a partially made redd. The

unfinished redd consisted of a pit about 7 in. deep, 24 in, across, and 18 in. long, with a mound below it. Conditions were such that the movements of the female could be fairly clearly observed, while any movements made by the male of the kind interpreted as milt shedding in the case of brown trout would not have been observable. A net was set 8 ft. below the pit in such a position that practically all of any ova failing to lodge in the pit must have drifted into it. During fifteen minutes the female left her resting position in the centre of the pit twenty-seven times, in each case taking up a position against the upstream wall of the pit. There she made movements identical with those already described in the case of female quinnat salmon and brown trout. Material was dislodged by her actions, the heavier material coming to rest in the pit and on the lower portion of the inclined plane at the downstream end of the pit. The lighter matter lodged higher up on the mound or was carried below. After fifteen minutes the net was examined and no ova had lodged in it. The fineness of material between the summit of the mound and the net would have prevented eggs lodging there before they reached the net. An examination of the redd disclosed ova beneath stones on the lower side of the bottom of the pit at a depth of 2 in. No ova were found higher up on the mound. The position of the ova found and the amount of material observed to be moved left no doubt that the ova found had been shed during the fifteen minutes.

Brown trout enter School Creek, at Inchbonnie, from Lake Poerua in order to spawn. In 1934 a trap was maintained in this creek throughout the spawning-season. Females entering the trap numbered sixty-eight specimens. The weight, in grams, of ova produced by each fish was determined. For this purpose the ova from each fish were stripped into a separate receptacle. They were allowed to stand in water until they had lost their adhesive quality and ceased to increase their weight by the absorption of water. Ova were then weighed. Several fish were killed to check the efficiency of stripping, and a standard correction was made to all egg-production weights of stripped fish. Weights of ova produced were then plotted against length of fish. Productions of 190 gm. and 219 gm. of ova were shown for fish of 16·5 in. and 17·25 in. respectively. These are average productions; some variation in productivity of fish of like size occurs.

The area of usual spawning-water above the trap (in which female fish of spawning-size are very rarely found except in the spawning-season) was thoroughly inspected. No redds or maturing females were found. A marked female of 16·5 in. was then liberated, with a male, above the trap and was kept under observation. This fish made three redds; two of them were over 350 yards apart. When spent, the fish was removed. From these three redds 187 gm. of ova were recovered. This quantity is 1·5 per cent. less than the average weight of ova produced by fish of that length in School Creek. A female of 17·25 in. was liberated later with a male in the same area. This fish made one redd from which 211·3 gm. of eggs were recovered. This is 3·5 per cent. less than the weight of eggs produced by fish of this size. The average difference between ova produced and ova recovered is thus 2·5 per cent. How much of this loss may be attributed to eggs failing to lodge in the redds when the fish were spawning, and how much to the imperfections of the methods of recovery, is not known. It is considered highly improbable that all ova which had lodged in these redds were recovered.

It is convenient at this stage to repeat that the material used in earlier sections of this paper for the determination of the extent of losses taking

place in redds comprises samples only of the contents of these redds. No attempt was made to recover all the eggs or alevins from such redds. The single redd just discussed, made by the 17·25 in. trout, yielded 2,536 when the collection of the whole of its contents was attempted.

At least 97·5 per cent. of the eggs produced by brown trout lodge in the redds at the time of spawning, unless fish are interfered with. Present data do not admit of the quantitative expression of the non-lodgment loss when quinnat salmon and rainbow trout spawn. Observations suggest that, as is the case with brown trout, the great majority of the eggs produced by those two species are lodged in the places prepared for them by the parent fish, unless the parent fish are interfered with.

B. LOSSES IN THE REDDS.

1. The Non-fertilization Loss.

Of the ova that are safely lodged in the completed redds, some may not be fertilized. Samples in which any dead ova had suffered exosmosis or which were of such an age that dead ova might have decomposed too much to make recovery possible were not used for fertility determination. Suitable material abstracted from loss tables already given is presented in Table 17. No material is presented here from Harrys Creek, where the efficiency of fertilization was lower than elsewhere. For other purposes a number of males had been captured there in the vicinity of the redds subsequently dug and had been stripped of milt.

Table 17.

Species.	Stream.	Percentage Infertile Ova per Redd.
Brown trout	Slovens Creek ..	0·84, 0·30, 0·65, 0·55.
,, ...	Black Creek	1·21, 3·04, 0·00, 1·06.
,, ...	Waterfall Creek ..	3·27.
,, ...	Jim's Creek	0·00, 0·85.
,, ...	Searles Creek ..	0·00, 1·66.
,, ...	Bruce Stream	1·06, 0·00.
,, ...	Selwyn River ..	1·49, 0·83, 0·81, 0·00, 0·70, 0·33, 0·69, 0·00, 1·94, 0·52, 0·00, 0·89, 1·42.
,, ...	Winding Creek ..	2·23.
,, ...	Main Drain	0·44, 0·00.
,, ...	Avon River	1·74.
Rainbow trout ..	Winding Creek ..	0·30, 0·25.
Quinnat salmon ..	Broken River ..	0·79.
,, ..	Winding Creek ..	(5 pre-eyed redds average 1·95 per cent. with other dead).

Taken as a whole, the material indicates a uniformly high efficiency of fertilization in the ova of all three species. The brown-trout material represents thirty-two redds in ten different streams. It comprises 9,330 specimens, of which 78, or 0·83 per cent., were infertile. In different redds the efficiency of fertilization ranges from 100 per cent. down to 96·73 per cent.

2. Subsequent Losses.

Where the total loss in a redd exceeds 3·3 per cent. the explanation should be found in causes other than initial infertility.

When ova of all three species were artifically stripped and fertilized and incubated under arbitrary conditions no substantial loss was found to occur which was not the product of the arbitrary conditions. Heavy losses could be produced at will by handling ova when they were very sensitive to concussion, or by reducing the water-supply and suffocating them. Losses were conditioned by the degree of care taken. There was nothing to suggest that the ova of some fish died through inherent weakness, when the ova of other fish, incubated under like conditions, did not. After hatching, a proportion of alevins developed yolk-sac dropsy, or "blue-swelling," when reared in artesian well water, but not when reared in Kashmir boxes in streams. "Curvatures"—these are alevins suffering from a spinal disorder—occurred among the alevins of the three species. Alevins, whether suffering from yolk-sac dropsy or the spinal disorder, lived for some days before dying. Only one alevin suffering from yolk-sac dropsy was found in a natural redd—a brown trout redd in the Selwyn River. No alevins suffering from the spinal disorder were found in natural redds. The facts suggest that such losses of alevins as occur under artificial conditions are largely the product of those conditions.

Day (*loc. cit.*) states that there is a great mortality among the eggs of young trout and that the death-rate is lower among the ova produced at the second spawning. He records that only "about a dozen" ova hatched from a batch of "about 500," artificially stripped from a two-year-old Lochleven female. Day was referring to ova which had been artificially stripped, fertilized, and incubated. His findings, therefore, have not necessarily any application when fish spawn under natural conditions. If they have any application under natural conditions, then heavy losses should occur in certain redds in streams in which a substantial proportion of the trout are spawning for the first time.

In 1934 a trap was maintained throughout the spawning-season in Black Creek. Scales were taken from a fair sample of the fish entering this stream. Mr. A. W. Parrott kindly read these scales for the writer. The readings show that 17 per cent. of the female brown trout were first spawners. Thus approximately one redd in six should show an exceptionally heavy loss, if the eggs of these fish are as unsatisfactory as Day claimed. Day records a loss of approximately 97 per cent. of the eggs of a first spawner before hatching. The heaviest loss of ova recorded in any of the sixteen redds in Black Creek was less than 12 per cent. at the time of sampling. It is not unreasonable to suppose that some of the thirty-four redds of brown trout from which ova were obtained in the Selwyn River were made by first spawners. Yet the heaviest loss in any one of these redds was less than 11 per cent. at the time of sampling. A female trout of $10\frac{3}{4}$ in. was permitted to spawn in a controlled area in School Creek. When spent, the fish was recovered, and scales were submitted to Mr. Parrott, who stated that the fish had not spawned in any prior year. This was the smallest female which entered School Creek in 1934. A few eggs recovered from this fish were quite distinct in colour and size from those produced by any other fish in this stream that year. A sample of eggs recovered from the two redds this fish made showed a loss of less than 1 per cent. Of the eggs recovered, eighty-seven were transferred to a hatchery and they produced eighty-four healthy alevins.

In view of the foregoing, Day's statement is not accepted as applicable to ova deposited in natural redds. It is proposed, therefore, to accept, as a hypothesis, that environmental factors, rather than inherent weakness,

nay be looked to for the causes of all heavy losses in natural redds. Losses n different streams and in different redds are hereafter examined in this ight.

3. Losses of Fertilized Ova.

Loss consequent on movement of ova, by floods, or by subsequent spawners, or consequent on redds being left by a stream changing its course, will be dealt with later. In this particular section only losses in redds not affected in any of these ways are considered.

The bulk of losses which, irrespective of species of fish, occur in varying intensity in different streams and in different redds in the same streams are attributed to a common factor. It will be shown that where redds are very clean losses are very slight. Where redds are very dirty losses are heavy. The conditions which invariably accompany heavy loss have been noted. The immediate cause of the loss is not known. There is sufficient evidence to show that where permeability is low there is a greater loss than where, other conditions being equal, the redd material is more permeable. There is insufficient evidence to show convincingly that the immediate cause of loss is suffocation on account of lack of oxygen.

For the moment the other important variable in incubation conditions—namely, temperature—will be ignored, and consideration will be limited to the problem in its simplest form.

Harrison(12) made a series of experiments with the ova of either sock-eye or quinnat salmon to determine which of a number of kinds of bottom material was most suitable for the artificial planting of ova. They show that the finer the material is the heavier is the loss. Thirteen plantings each of 500 eggs in "good gravel" gave numbers of fry varying from 401 to 487, the loss in the average case being 9·6 per cent.

A: 500 eggs in good gravel from hickory-nut up to walnut size, with very little sand, gave 420 fry.

B: 500 eggs in gravel from pea-size to hickory-nut size gave 350 fry

C: 500 eggs in same as B, but with a top layer of silt, gave 325 fry

D: 500 eggs in fine gravel with a small amount of clay and sand gave 299 fry.

E: 500 eggs in fine gravel with much clay and sand gave 170 fry.

Calderwood comments that, "these tests are very interesting and show clearly the benefit of coarse gravel, but they also show that under the conditions which would be naturally selected by fish the hatch is exceedingly good and not far short of the high percentage which is claimed in hatchery work." The present writer cannot wholly agree with these dicta, for, in New Zealand, the coarse, clean gravel which Harrison shows gives the best results was not observed to be selected generally by spawning fish. It cannot be assumed that exactly the same percentage hatch will result, when eggs are artificially introduced to a certain mixture of material, as will result when the ova are deposited in it by a fish. It is, however, reasonable to expect that differences, similar to those shown to occur by Harrison's experiment, will result in different mixtures, whether ova are artificially or naturally introduced into such mixtures.

If anything in the nature of an exact determination of the permeability of a redd were attempted with a view to ascertaining whether ova received a sufficient amount of oxygen, the following factors would have to be considered. Further, they would have to be considered at successive growth stages: (1) The number and size of ova per unit volume of bottom

material; (2) their oxygen-requirements; (3) the permeability of the redd material; (4) the contours of the redd; (5) the rate of flow of water over the redd; (6) the amount of available oxygen per unit volume of water; (7) water-temperature. It was not possible to measure all these factors in the field.

General impressions, in the case of trout-redds in Slovens Creek in 1932, were that heavy mortality occurred in redds in which much fine material—mainly clay—was present in the egg-pockets. It was noticed that, normally in redds there, there was a definite silt "crust" overlying the cleaner material in which eggs were found. It was only when this fine material extended from the surface down into the egg-pockets of the redds that heavy losses were found. In 1933 samples of egg-bearing material were taken from a number of redds. These samples are not strictly comparable because of the different stages of development attained by their contents. It is considered, however, that the samples are sufficiently indicative of the composition of the materials of the egg-pockets of redds, both of the streams and of the particular areas of the streams they represent, to have some value for purposes of comparison. Analyses of these materials are given in Table 18. They were screened through square mesh sieves of different sizes. The sizes of the meshes given are the distances, in inches, between opposite sides of apertures. Material of over 3 in. (a few stones only) has been excluded.

Table 18.

Species	Quinnat Salmon.	Brown Trout.						
Stream	Winding Creek.	Slovens Creek.				Searles Creek.	Bruce Stream.	Pigeon Creek.
Redd Index No.	Q.W.23.	Q.W. 1.	20.	5.	8.	26.	1.	6.	2
Dry Weight in Pounds	18·32.	14·80.	12·62.	20·21.	17·67.	16·00.	14·62.	14·69.	13·37.
Percentage over 1·25 in.	31·40	35·47	19·17	41·75	28·37	13·67	37·32	41·06	47·30
Percentage over 0·50 in.	21·84	21·95	19·48	22·33	22·69	23·43	23·10	20·85	22·96
Percentage over 0·25 in.	24·57	16·89	33·16	14·73	19·85	28·90	15·99	15·53	11·94
Percentage over 0·10 in.	16·37	15·20	20·20	11·05	15·60	19·14	11·99	12·12	8·66
Percentage over 0·06 in.	2·56	4·64	3·36	3·37	4·25	3·90	4·66	2·76	2·34
Percentage over 0·03 in.	2·29	4·22	2·33	3·07	4·43	3·31	5·33	5·53	2·57
Percentage under 0·03 in.	0·93	1·58	2·07	2·61	4·75	7·42	1·55	2·12	4·21

The only material in these screenings likely to cause any marked degree of turbidity during the disruption of redds is that of less than 0·03 of an inch. It is proposed to examine the general impression that dirtiness in redds is the dominant condition which accompanies heavy mortality in redds, in the light of the most exact data given in Table 18.

Existing data, in some cases, scarcely justify the correlation of losses with environmental factors attempted in Table 19. In order to see if, and to what extent, mortality is dependent on the dirtiness of redds and on water-temperatures it is desirable to have a large number of samples of material from redds of fish of one species. Further, it is desirable that all such redds should be sampled when the ova in them are at a like point of development. Given such material, it would be seen to what extent, if at all, it would be

necessary to consider other factors, such as rate of flow over the redds or density of massing of ova.

TABLE 19.

Species	Quinnat Salmon.		Brown Trout.						
Stream	Winding Creek.		Slovens Creek.				Searles Creek.	Bruce Stream.	Pigeon Creek.
Redd Index No.	Q.W.23.	Q.W. 1.	20.	5.	8.	26.	1.	6.	2.
Percentage of fine material	0·93	1·58	2·07	2·61	4·75	7·42	1·55	2·12	4·21
Percentage of development of contents of redd	13	69	37	13	15	53	10	81	26
Pre-eyed loss, per centum	1·10	2·84	0·33	0·55	3·39	59·77	0·00	4·20	94·12
Maximum temperature, degrees C., in pre-eyed period	9	9	8	6	6	8	3·5	11	12
Approximate age of redd, in days	62	12	78	22	24	103	..	..	21

Firstly, these analyses confirm general impressions in that salmon-redds in Winding Creek were the cleanest of all redds encountered, while the dirtiest redds were those of brown trout in Slovens and Pigeon Creeks.

Secondly, Slovens Creek data show that analyses of redd materials will indicate differences in types of spawning-areas to a greater extent than differences in age of redds. For instance, while Redd 20 is substantially older than Redds 5 and 8 it is also much cleaner.

Thirdly, mortality is greatest in streams in which redds are dirtiest. To illustrate this point only losses in the pre-eyed stage are used. This is the stage in which mortality is greatest. The initial non-fertilization loss may be as high as 3·27 per cent. Losses of less extent cannot safely be attributed to environmental factors. The following facts are significant :—

(1) The average amount of very fine matter in the two samples from salmon-redds in Winding Creek was 1·25 per cent. These redds were typical of salmon-redds generally in that stream. The pre-eyed loss in quinnat-salmon redds in that stream was 2·13 per cent. Redds of brown trout in the Selwyn River and in Black Creek impressed as being comparable in cleanliness with those of salmon in Winding Creek. The estimated losses in the pre-eyed stage in trout-redds in these two streams were 2·95 per cent. and 4·04 per cent. respectively.

(2) The average amount of very fine matter in four redds of brown trout in Slovens Creek was 4·21 per cent. The estimated loss in the pre-eyed stage in that stream was in excess of 20·16 per cent.

(3) The amount of very fine matter in a redd in the Bruce Stream was 2·12 per cent. A loss of under 6 per cent. in the pre-eyed stage is indicated in that stream.

(4) The amount of very fine matter in a redd in Pigeon Creek was 4·21 per cent. The loss for virtually the whole of the pre-eyed period in that redd was 94·12 per cent.

The facts show that mortality is heaviest in streams where the materials comprising the redds are dirtiest. An examination of data from Slovens Creek alone shows that in the same stream, where a greater uniformity of other environmental factors exists, the dirtiest redds show the heaviest losses. In Redd 26 in this stream the pre-eyed dead recovered amounted to 59·77 per cent., as against 0·33 per cent. in the much cleaner

Redd 20. In thirteen redds in Slovens Creek the loss in the pre-eyed state exceeded 10 per cent. Of these, six, including Redd 26, were in the immediate vicinity of one another, and the materials comprising them appeared to be very similar. Six of the remaining seven redds were noted at the time of disruption to be much dirtier than other redds in which losses were slight. No note was made of any special conditions in Redd 22, the remaining redd, and no explanation is tendered for this particular loss. This redd was one of the earliest redds dug in 1932 and ova were collected from it for the determination of losses before the writer had formed any intention of attempting the determination of the causes of losses.

In only two salmon-redds did losses in the pre-eyed stage exceed 5 per cent. The loss in one of these is attributed to special circumstances, to be mentioned later (see page 83). In the other, Redd 18 in Winding Creek, there was a total pre-eyed loss of 13·51 per cent. This redd appeared particularly dirty compared with Redd 20, a slightly older redd in the same stream, which was dug out on the same day and which showed a loss of only 1·05 per cent. It was much dirtier than the still older Redds 1 and 23, from which samples of material were taken.

Fourthly, where redds are equally dirty there are slight indications that mortality may be highest where water-temperature is highest. Such a finding might be expected if suffocation were the immediate cause of death. The highest point reached in temperature during pre-eyed development in Redds 20 and 26 in Slovens Creek was 8° C. in each case. It is clear that one lot of eggs was able to endure at that temperature without heavy loss in material containing 2·07 per cent. of very fine material, while the other lot could not in a mixture of material containing 7·42 per cent. of fine matter. The loss figures for Redd 8, in Slovens Creek, in which there was 4·75 per cent. of fine matter in the egg-pocket, is not necessarily the total loss in the pre-eyed stage. Eggs in that redd had not completed pre-eyed development. Two redds in Pigeon Creek at Inchbonnie showed exceptionally heavy losses. These two redds were side by side, and the percentage of fine matter they contained, which is shown in one case to have been 4·21 per cent., appeared to be much the same in either case. Although the data given in Table 21 show the same amount of fine matter in the average case, in Slovens and Pigeon Creeks, a much greater loss is indicated in the latter stream than is shown in the former one. The highest point of temperature reached during pre-eyed development was 8° C. in Slovens Creek and 12° C. in Pigeon Creek. There was a considerable difference in the losses in the pre-eyed stage in the redds in Pigeon Creek. In Redd 2 there was a loss of 98·12 per cent., and the live ova in the sample had still a few hours to go to reach the eyed stage. In Redd 3 the total pre-eyed loss was 65·18 per cent. Temperature records are meagre, but they show a temperature of as high as 12 during pre-eyed development of the contents of Redd 2 and of 8·5° in the case of the contents of Redd 3.

Where heavy losses occur—for instance, in Slovens Creek—mortality is much higher before eyeing occurs than at any later time. The few exceptions to this rule will be discussed at a later stage of this paper. If losses occur through suffocation, they should normally fall much more heavily in the eyed stage than in the pre-eyed stage. This is so unless oxygen-requirement of ova decreases with increased development sufficiently to offset the effects of the usual reduction of water-supply and the usual increase in temperature.

The peak of the incidence of mortality in the pre-eyed stage cannot be accurately determined from data available. In most cases where heavy losses occurred, and particularly where decomposition of dead ova had advanced far, the stage of development attained before death could not be ascertained very accurately. In Redd 7 in Slovens Creek a loss of 14·94 per cent. had taken place before ova had passed the 14-per-cent.-development stage. In two cases deaths were still occurring at about the 19-per-cent.-development stage. It is quite clear that the loss period normally lies between the 10-per-cent. and 20-per-cent. points of development. Evidence shows a period of vulnerability. It does not show any particularly vulnerable point within that period.

Eggs are much more sensitive to concussion before they reach the eyed stage than thereafter. They are sensitive in the stage in which heavy losses occur. The questions arise as to whether they are most sensitive during the period of heavy loss within the pre-eyed stage, and as to whether circumstances suggest concussion as a probable cause of death. It was clear, from the behaviour of ova dug from redds at different growth-stages, that eggs were less sensitive to concussion immediately following deposition, and again immediately preceding eyeing, than in the intervening period. Except immediately after fertilization, they were more sensitive to concussion in the first half of the pre-eyed period than in the latter half—that is to say, the period in which ova are most sensitive to concussion precedes that in which the heavy losses occur. Experience gained in the handling of ova at sensitive stages suggests that the deposition of fine silt particles could not cause loss by concussion. If it does cause loss, then such loss should occur when ova are most acutely sensitive. Heavy losses in the pre-eyed stage are known to occur some time after ova have ceased to be acutely sensitive to concussion.

Of the thirteen redds of brown trout in Slovens Creek in which losses were very heavy, nine were in artificial channels made for the stream when the original course was straightened and broadened when the Midland Railway line was built. Vibration during the passage of trains was very noticeable on the bank of the stream within a few feet of several of the redds. If the vibration extended to the bed of the stream, and caused losses, such losses would have occurred when ova were most acutely sensitive to concussion. Actually they did not. They would also have been greater in the redds nearer the railway-line than in those farther away. This was not the case, however.

No samples of ova in very dirty redds completed pre-eyed development without heavy loss. In a number of cases dirty redds in which ova had not completed pre-eyed development were examined, and losses were slight. They were all redds of brown trout. One was in Slovens Creek, one was in School Creek, two were in the Avon River, and three were in Winding Creek. In each case, however, ova were less than 15 per cent. developed. Conditions suggested that heavy losses would have taken place had these redds been left.

The evidence of heavy mortality being a consequence of an excess of fine matter in redds is threefold—firstly, there is the result of Harrison's experiments; secondly, there is the writer's general impression that losses were heaviest in natural redds in which the most turbidity was produced on disturbance of material in the egg-pockets; thirdly, there is the correlation of measured mortality and measured fine material in natural redds. Circumstances suggest that suffocation may be the immediate cause of death.

There is insufficient evidence to show convincingly whether or not this is so. While the approximate period of susceptibility to heavy loss has been noted and the dominant condition which controls the extent of it has been determined, the immediate cause of death is not known.

4. Mortality consequent on Earlier Mortality.

Saprolegnia has, so far, been discussed only as a decomposition agent and not as an original cause of loss. Rutter (*loc. cit.*) states that fungus does not normally attack live ova. At the same time he adds that "fungus grows rapidly on dead eggs, and the filaments extend in all directions and entwine the adjacent eggs in a thick mat. This interrupts the circulation of the water and often smothers the eggs so matted. When eggs are smothered the embryo turns white before the yolk is addled, so that dead from that cause can be distinguished." The present writer's observations under hatchery conditions confirm the quoted part of Rutter's findings. In natural redds, with three exceptions in School Creek, coagulated embryos were not noted in ova, save where exosmosis had occurred. The lack of such ova suggests that exosmosis normally follows within a few days of the death of fertile eggs. Its occurrence might be accelerated by movement during redd disruption.

It was common to recover, from redds showing a high mortality, matted masses of fungussed ova of different growth-stages. It is certain that redd disruption must have led to the severance of many such clusters of dead before they reach the net. Reference has already been made to the normal dense massing of ova in redds and to the variation in the incidence of fungus. It will be recollected that in the case of Slovens Creek pre-eyed losses very greatly exceeded eyed losses. It seems certain that a considerable proportion, and possibly the great majority, of eyed losses not only in Slovens Creek, but elsewhere, are simply losses consequent on the earlier loss in the pre-eyed stage. *Saprolegnia* appears to be essentially a secondary cause of loss varying to a considerable extent in accordance with extent of earlier losses. Redd No. 23 in the Selwyn River was unusual in that all the ova comprising the 8·9-per-cent. loss in the pre-eyed stage were fungussed. This was one of the two "dry" redds. The dead ova were bound together in one mass by *Saprolegnia*. It seems not improbable that it flourished better under the particular conditions existing in this redd.

5. Sundry Heavy Losses in Redds.

The loss of 5·51 per cent. in the pre-eyed stage, noted in a salmon-redd in Winding Creek (Redd 24), was the only loss noted in a sample which could be attributed to concussion. In this case, while the bulk of the ova were satisfactorily lodged, as is normal, a small proportion was lying loose under stones in the surface of the redd in the depression at the upstream end. These ova were not securely held and were in such a position that they were likely to move about in the water percolating beneath the stones. All these ova were dead.

Three contiguous redds in School Creek—Nos. 6, 7, and 9—presented unusual features. Their composition was unusual in that the materials comprising them consisted of grit, sand, and finer matter with a comparatively small amount of coarser material. In each case a few dead ova, in which the embryos were coagulated but exosmosis had not occurred, were taken. Each of the redds was dirty, and in each the loss, as is usual in such cases, was heavy. They were also quite normal in that the oldest and dirtiest

edd, No. 9, showed the heaviest loss. Yet in this last redd the loss in the yed stage was over three times as heavy as in the pre-eyed stage. These edds had not been kept under observation, being below the usual bservation area in this stream. It is just possible that a contributing actor to the later losses in Redd 9 was the deposition of fine matter in it as Redd 6 was made immediately upstream from it. The contents of the former edd would be about 16 per cent. developed at this time.

C. FLOOD LOSSES.

Flood-effects are best considered under two heads: (1) Those which esult only in the deposition of fine material in the redds; (2) those which esult in substantial changes in the contours of redds.

(1) Deposition of Silt.

There is always a tendency for a redd, which at the time of making has been cleared of fine material, to resume the original character of the urrounding bed. This is so whether or not floods occur. All floods assist he flow of fine matter into the redd from the surrounding stream-bed. When a rise in water-level is accompanied by turbidity, deposition of matter carried in suspension by the water takes place in redds. The extent f this type of deposition, as opposed to drift, will depend on the degree f turbidity produced rather than on the extent of the increase in volume. n Black Creek a many hundredfold increase in volume did not result in the eposition of any quantity of fine matter in redds, turbidity being egligible. In Winding Creek, during a less than twofold increase in volume, ttended by intense turbidity, considerable quantities of fine matter enetrated to egg-pockets in redds of brown trout. The time and extent of he deposition of fine matter will determine the extent of any resultant ss. If such deposition takes place only after the completion of pre-eyed evelopment its adverse effects should be less than if it occurs during e-eyed development.

Judging by the known heavy losses in dirty redds elsewhere, and by e particularly dirty state of redds of brown trout in Winding Creek, it considered that these redds in Winding Creek would have shown heavy sses if they had been sampled later. Quinnat salmon in that stream awned earlier than brown trout did. Their eggs, buried at twice the pth of those of brown trout, were less affected by silt. Further, they had mpleted pre-eyed development before the worst flood came. Redds of rown trout were sampled immediately after the flood and before the loss curred which might have been expected to result. Rainbow trout spawned fter the flood and cleared the dirty material from the bed as they made heir redds.

The extent of the loss caused by this flood-effect has not been measured. t is interesting to note, however, that in 1932 certain brown-trout redds n Slovens Creek became extremely dirty without the assistance of any loods. In 1933, in Winding Creek, which has a much cleaner bed, redds emained relatively clean until affected by floods. The susceptibility of he contents of redds to losses of this type will depend on: (1) The nature f the stream-bed; (2) the extent of the increase in volume; (3) the degree f turbidity of flood-waters. The dirtier the stream-bed is the greater ill be the flood-time drift of fine matter into the redds. All floods will ncrease this drift, but the passage of turbid flood-water through the redds ill cause, as well, the deposition of material carried in suspension.

(2) Major Changes in Redds.

It has been stated that the mounds of redds tend to resume the level of the surrounding stream-bed: further, that the composition of the surface material tends also to resume the character of the surrounding bed. The major flood-effects, about to be discussed, are those which result in more substantial changes in redds:—

(*a*) Redds may be washed completely away.
(*b*) Redds may be so left by a stream changing its course that alevins, even should they hatch out, may be unable to regain the stream.
(*c*) There may be a heavy deposition of material on the redds.
(*d*) The surface material may be removed by scouring.

All these flood-effects were noted as affecting salmon-redds. All caused losses. It did not prove possible in all cases to measure accurately the extent of the losses. The illustrations given, with one exception, are of the effects of floods on salmon-redds in the Broken River system. The floods in this river system resulted from the abnormal weather conditions of 14th July, 1933. Broken River itself, in the wide flood-bed, which extends from the bottom of the short gorge immediately below the old coal-mine down to below the entrance of Slovens Creek, changed its course considerably. A factor which must have contributed to the modification of the old course was the entrance of a large quantity of coarse material from a flood-channel on Scrubby Flat at the upper end of this reach. In Winding Creek an inrush of stones from a very steep storm-water course occurred at the north-eastern extremity of Broken Hill. This watercourse is shown in Plate III. It dammed the whole stream for a few hours, enabling the water above the barrier to drop much of the material which it had been carrying in suspension. The fine matter in suspension came from a small landslide on Mount St. Bernard some miles higher up. When the barrier carried away, much of the coarse matter comprising it was deposited in the stream-bed below. Extensive modifications of the stream-bed took place for 50 yards below this point. The stream is less confined in this particular area than anywhere else in its course. Enough of the barrier was left to cause the stream above to stabilize at a higher level than below. The result was that much of the fine matter which had settled above, while the flow was impeded, remained subsequently. In the lower portion of Slovens Creek modifications were generally slight. In a few places scouring to a depth of 12 in. occurred.

(*a*) *Redds washed away.*—Of a total of 26 redds under observation in Broken River, 7, or 26·92 per cent., were washed completely away. Ova in some of these redds were nearing the eyed stage, while in others they had recently reached the eyed stage. The pre-eyed ova, which were still relatively sensitive to concussion, may safely be regarded as total losses. The chances of any disturbed eyed ova surviving are problematical.

(*b*) *Redds left by the Stream.*—Five, or 19·22 per cent., of the redds marked in Broken River were left in superficially dry river-bed by the stream changing its course. These redds were not opened up by the writer. It is probable that, as in the case of redds of brown trout in the Selwyn River, water percolated beneath the dry surface and ova survived for some time. One of these redds was left 45 yards distant from the new course. Others were not so remote. At subsequent dates flood-waters passed over three of these redds and may have permitted alevins to escape. Two redds over which flood-waters did not pass subsequently may be

egarded as total losses. A salmon-redd in Winding Creek was affected n the same manner as were those in Broken River. A slight change of ourse occurred immediately below the barrier formed by the entrance of he storm-water channel. No later flood passed over this redd. Therefore levins could not have escaped from it.

(*c*) *Deposition of Material on Redds.*—This occurred to two salmon-edds in Winding Creek and to two in Broken River. The loss, in the levin stage, of 23·54 per cent., noted in Redd 25 in Winding Creek, is ttributed to the only abnormal feature noted. There was a flood-deposit f very dirty material, to a depth of 5 in., on this redd. Of the total of 58 alevins obtained from it, the first 550 to enter the net were practically ll alive. These were obtained at a depth of about 9 in. below the altered evel of the stream-bed, and were in relatively clean material. The emaining 308, of which about two-thirds were dead, were taken from in. of dirtier material actually below and in part slightly downstream rom the cleaner material which yielded the good sample. There is no oubt that a large proportion of these dead were actually to the downstream ide of the live, though a certain number were actually underneath the aterial from which the live were taken. The peak of mortality had assed. Only two of the total 202 dead had recently died, the great ajority of the dead being in an advanced state of decomposition and tinking offensively. The occurrence of a clean stratum of the nature escribed, between two dirtier ones in disturbed redd material, is quite nusual. The normal redd of any age consists of two strata, a dirtier rface one, over a cleaner one, which rests on the stable undisturbed ottom. It is significant that Redd 28, which, on the same day, yielded ,184 alevins all alive and of greater age, had been subjected to the same ood that damaged Redd 25. There was no deposit on top of this redd. he surface material, however, contained a great amount of very fine atter. The underlying material from which alevins were obtained was uch cleaner than that in which dead were found in Redd 25. It may be portant to note, in connection with this heavy alevin loss, that the ad alevins had reached particularly dirty material (indeed, it extended m where they were found nearly to the original egg-level) before they had ched the stage at which Wood (*loc. cit.*) has shown that the oxygen-quirements of brown trout dropped considerably. Just what significance n be attached to the position of the dead alevins in relation to the live it difficult, in view of the lack of precision of the observations, to say. If, wever, suffocation were the cause of loss it would be reasonable to ppose that alevins at the upstream end of the redd would have a better ance of surviving than those at the lower end, to which water, from which me oxygen had already been removed, was passing. The other redd in inding Creek was at the upper end of the barrier of coarse material rought in by the storm-water course. The deposit was about 15 in. deep mediately above where the eggs had lodged in the redd. This deposit ll away sharply on the upstream side to meet the original level of the d about 3 ft. upstream from the ova. This portion of the barrier mained after the flood, when the rest had been carried away. Unlike the posit on Redd 25, the deposit in this case, while of greater depth, was of arse, clean material. A sample of ova had been taken from this redd fore the flood. A further sample was not taken, because it would not ve been possible to distinguish losses caused previously by the effects of gging.

On the two redds in Broken River there was a deposit of about 9 in. of fairly clean material. Water continued to flow over them. These redds were not sampled after the flood.

It has been stated that, with one exception, only salmon redds were observed to suffer from major flood-action. Station Creek is a tributary of Lake Poerua, near Inchbonnie. It follows a short and very rapid course over a mica-schist bed from the western face of the Mount Alexander Range. In the middle of April, 1934, during exceptionally heavy rain, a landslide occurred up this stream, and a large quantity of rock and timber entered the bed. Washouts occurred at the approaches to the railway-bridge across the stream. Brown trout later spawned in the stream. In August, when the bed was still overcharged with debris, the stream, during a heavy flood, scoured out a new channel across a bend (see Plate XI). The result was that material to a depth of from 4 in. to 12 in. was deposited on redds below this point. There is no doubt that redds must have been

PLATE XI.—Station Creek, Inchbonnie, showing the change of course (from dotted line to unbroken line) which resulted from the entrance of landslip debris.

adversely affected by this deposit. No attempt was made to collect material from redds in this stream.

(*d*) *Surface-scouring.*—Redd 3, a salmon-redd in lower Slovens Creek, suffered in this way. Material to a depth of approximately 12 in. was removed from the surface of the redd when the ova were in the eyed stage. Eggs were found within 3 in. of the new surface. Following this flood sediment settled among the eggs, with the result that they were recovered from very dirty material. It is exceptional for losses in the eyed stage to exceed those in the pre-eyed stage. In this case there was a loss in the eyed stage of 8·62 per cent., as against a pre-eyed stage loss of 3·37 per cent. This abnormal loss is attributed to the abnormal condition of the redd.

Slight surface-scouring occurred in six redds in Broken River. It did not appear that a depth of more than 3 in. of material had been removed from the surfaces of these redds. These redds were not sampled.

Flood-effects in relation to Time.

It has been shown that three quinnat salmon redds in Winding Creek were adversely affected by a flood in 1933.

Mr. J. H. Kidd, whose letter has already been referred to, has a knowledge of conditions in the Broken River system which extends back to before 1922, when salmon are first known to have entered Broken River. He states that only once previously to 1933 has he known Winding Creek to be discoloured. Confirmation of Mr. Kidd's views as to the rarity of floods as severe as that of 14th July is provided by rainfall records kindly furnished by the Waimakariri River Trust. At the Flock Hill Station, near the head of Winding Creek, in the six years 1928 to 1933, inclusive, only two rainfalls of over 3 in. in a twenty-four-hour period are recorded: one of 3·04 in. on 10th April, 1931, and one of 3·8 in. on 14th July, 1933.

In Broken River flood-effects were much more pronounced than in Winding Creek. Of twenty-six redds under observation in the former stream, seven, or 26·92 per cent., were washed away, while thirteen others were affected either by scouring, by deposition of surface material, or by change of the course of the stream. Losses have been shown to have been caused in salmon-redds which were affected as the thirteen were. Further, prolonged flooding caused a more than normal deposition of silt in all redds.

Some deposition of silt must take place in redds in Broken River in most winters during minor freshets. Normally floods likely to cause major changes in redds do not occur before October. Less commonly spring floods commence in September. Although normal spring floods are substantial, they are much less severe than that noted in July, 1933. It was clear, from the deposit in the river-bed, that some years had elapsed since a flood of like severity had taken place. The rate of incubation of quinnat-ova at different temperatures is not known. If the relative rates of development of salmon-ova and alevins and those of brown trout are the same at lower temperatures as at 9° C., quinnat alevins must emerge from the redds in Broken River usually about the end of September or the beginning of October. Roughly, the time of redd-emergence will approximate with the usual time of commencement of spring flooding. Mr. Kidd's statement that he has never, previously to 1933, known severe winter flooding—that is, flooding comparable with spring flooding—to occur is very important. It is clear that normally salmon-redds in Broken River are not subjected to severe floods. The very heavy loss of 1933 must be regarded as an exceptional occurrence, the only one of that extent in fourteen years. It is not improbable that from time to time smaller losses have occurred through spring floods starting in September. A loss such as took place in Broken River in 1933 could very well account for the partial failure of a year class.

The Waimakariri River, into which Broken River flows, floods principally as a consequence of the same weather conditions which cause the latter stream to flood. Only the more severe of the north-west storms, which cause flooding in the Waimakariri, reach the headwaters of Broken River. Records, provided by the Waimakariri River Trust, of floods causing rises of 4 ft. or more in the Waimakariri at White's Bridge, about four miles from the sea, are given in Table 20.

Table 20.—Height, in Feet, of Floods of over 4 ft. in the Waimakariri River at White's Bridge.

	1928.	1929.	1930.	1931.	1932.	1933.
January ..	..	4·3	5·4, 8·4, 9·0	4·0, 4·0, 6·5, 4·8	4·1, 4·2	..
February ..	..	..	..	5·9, 7·5	4·4	8·8, 9·2, 7·3
March ..	..	5·1	..	5·3	..	5·2
April ..	7·1	..	..	9·4, 7·8	4·6	6·0, 6·1, 6·8 6·2
May	*4·8*	..	..	*5·5*	*4·7*	*5·2, 7·0*
June ..	..	*4·1*	..	*4·2*	..	..
July	..	*4·6*	..	..	..	*8·0*
August ..	..	*4·1*	..	..	..	*5·2*
September ..	..	*5·8, 5·8*	..	..	..	*4·6*
October ..	7·6, 5·1	5·6	5·9	9·9	5·0, 4·8, 4·4	4·9
November ..	4·6	6·0, 5·4, 5·0	4·3	..	6·7	..
December ..	..	6·2, 5·4, 5·3, 7·0	5·7	6·2, 5·0	..	6·5, 5·1, 5·2, 6·1, 4·4

Salmon ova or alevins are to be found in redds in Broken River from May to September, both inclusive. The severity of the flood of mid-July in Winding Creek and Broken River is shown in the Waimakariri records. It will be noted that this flood of 8 ft. is the most severe winter flood recorded in the six years. So far as the data go they indicate that conditions were exceptionally favourable in 1930, good in 1928, 1931, and 1932, bad in 1929, and exceptionally bad in 1933. For several reasons it is not proposed here to attempt to correlate spawning conditions with the size of subsequent runs—firstly, the relative ill effects of minor and major floods have not been accurately enough determined: secondly, insufficient collections of scales have been made to enable the proportions of different year classes to be determined and to show the extent of changes in the composition of the annual runs; thirdly, there is no evidence to show what proportion of the fish hatched in any river system return to it to spawn. There is abundant evidence of a dispersal of acclimatized stock from the Waitaki River, some 175 miles south along the coast, but no evidence to show how many fish hatched in the Waimakariri return to it, or come to it from other waters: fourthly, no data are available to show to what extent the natural mortality of older quinnat fluctuates. The fact that in some years a large but indefinite proportion, and in other years a very small (but equally indefinite) proportion, of adult quinnat are badly scarred by predatory fish suggests that a considerable variation in the death-rate may occur. Until such points as these are cleared up it will not be possible to say whether or not the extent of runs can be predicted by reference to past spawning-conditions.

Susceptibility of Streams to Flooding.

Observations on streams when in flood are alone likely to be of any assistance in gauging the extent of deposition of fine material in redds. It would not, for instance, be possible to judge the extent of flood-time turbidity in such streams as Pigeon, Black, Winding, and Slovens Creeks by an examination of the beds of those streams when at normal water-level.

The extent of turbidity in flood-time does not necessarily bear any relation to the extent of the fine matter in the bed.

On the other hand, it is possible to judge by the deposit whether or not extensive modifications of a stream-bed occur. A stream-bed provides evidence of the severity of floods, but seldom of the times of the year in which they occur. At Inchbonnie a heavy crop of ragwort (*Senecio jacobaea*) seedlings in flood debris was evidence of the occurrence of a flood at the time that this plant seeds. It provided no evidence, however, that like floods did not occur at other times of the year. The extent of the mean annual rainfall in an area provides no indication of the extent of flood-time movement of stream-beds in that area.

Trout and salmon make redds in positions where they are least likely to suffer disturbance in flood-time. They choose areas where the bed is relatively stable and, very frequently, loosely cemented. They do not spawn in loose, rounded stones which will "flow" easily in flood-time. Nor do they choose sheltered positions in side eddies where a heavy deposition of silt might take place. It is considered that redds observed were very generally so placed that they would have been able to withstand the effects of all normal and seasonal floods. The only floods observed to alter redds substantially were abnormal, both in point of time and in point of volume. These substantial modifications of redds took place only in positions in streams where it was evident that modification of the stream-bed might occur during exceptional floods. There was only one such position in Winding Creek. This stream is generally confined to banks covered by vegetation and has a very stable bed. The 30 yard long wall of easily erosible material presented by the mouth of the storm-water channel coming off Broken Hill was the one exception. This channel was of very steep gradient. The bed of it comprises clean and partly rounded stones of up to 6 in. No vegetation grows in its course. Its size, in relation to Winding Creek, is such that it can, and under exceptional circumstances does, pour in sufficient material to dam up the permanent stream.

In the reach of Broken River where heavy losses occurred, the stream is not confined to vegetation-covered banks. There is, on the contrary, an extensive flood-bed, in parts 300 yards wide (see Plate I). The stream normally occupies only a small portion of this flood-bed. In parts it breaks into several smaller streams, which are divided by low-lying shingle banks on which only odd tufts of grass grow. The lowest areas of the flood-bed are devoid of vegetation. The highest areas carry the most vegetation. Before the flood of July, 1933, rotten logs, which would have broken up if moved, indicated the infrequence of the passage of flood-waters over the better grassed and higher river-flats. Only sounder timber occurred in the more recent and lower deposits. By reading the signs in the flood-bed it was not difficult to see whether any particular flood was a normal one such as might occur in any year, or an abnormal one such as might occur only once in many years.

Brown trout normally frequent and spawn in streams having more stable beds than those in which quinnat salmon spawn. It is clear that quinnat salmon and brown trout sometimes spawn in the same waters—for instance, in Winding Creek and the lower portion of Slovens Creek. So far as present data extend, however, they suggest that Broken River is more typical of salmon-spawning waters in Canterbury than Winding Creek is.

The streams in which redds of brown trout have been sampled for the purposes of this paper embrace most of the usual types of spawning-waters

of this species in the South Island of New Zealand. They include types of streams common in parts of the North Island. Both light and exceptionally heavy rainfall areas are represented. The streams at Inchbonnie include some flowing through a recently deforested area and some in an area in which deforestation was in progress. The materials comprising the beds of the different streams are very diverse in character.

In Slovens Creek redds of brown trout were marked when completed. For this purpose a ring of wooden pegs was driven into the bed of the stream round each redd. The depth to which these pegs were driven was approximately that at which the ova were buried. These redds were subjected to abnormal flooding in 1933. Yet no pegs were scoured out and, beyond a levelling in some cases of the surfaces of the redds, the redds suffered no substantial change. In no other streams were redds of brown trout marked in this manner. The fact that redds of sufficient age to contain well-eyed eggs and alevins could be recognized as such by surface contours in streams at Inchbonnie indicates an absence of serious modification during floods. Very heavy, though normal, floods are known to have passed over these redds before they were sampled. In the Selwyn River in Canterbury, generally the surface contours of the older redds in crowded spawning-areas had been lost through the disturbance of the adjacent portions of the bed by later spawners. In several instances, however, individual old redds in the area of permanent water were distinguished by their surface contours, and samples were obtained from them. This stream was subjected in the winter of 1934 to a series of floods. Although these floods were mild, if judged by Inchbonnie standards, they were moderate ones for the Selwyn River. This stream carried a much greater volume of water in the winter of 1934 than it does in the average winter. Only in Station Creek at Inchbonnie were the contours of redds of brown trout substantially modified by flood-action. In this case the modification resulted from an unusual occurrence—a landslide in the headwaters followed by a change of course. In Winding Creek a considerable change in the composition of materials comprising redds of brown trout resulted from landslide debris entering the stream during an abnormal flood.

With the exception of the Selwyn River, Station Creek, and a small portion of Winding Creek, the trout streams here discussed are normally confined by banks showing little or no evidence of active erosion. In the three cases mentioned, where either the presence of a flood bed or of signs of marginal erosion indicated that modification of the stream-bed during floods may result in losses in redds, all available data suggest that the occurrence of substantial losses will be very unusual.

D. SUPERIMPOSITION OF REDDS.

There is evidence that losses occur in the redds of brown trout through the formation of redds of late spawners on top of those made earlier. Before proceeding to a consideration of superimposition proper, brief mention may be made of another effect of late spawning-activity on redds made earlier. Where redds are made close to one another the composition of the material comprising an early redd may be altered by the drift into it of fine material disturbed in the making of a later redd. Any increase in the percentage of fine matter in the earlier redd so resulting will tend to be harmful. Further, the current of water passing over a redd may be reduced by the later construction of a redd immediately upstream from it.

Any losses caused in these ways are included in the losses ascertained from material collected, by the method of sampling described in this paper. Losses, if any, caused by the substantial modification of early redds without disturbance of egg-pockets have also been included. Where, however, later spawning-activity has resulted in the disturbance of eggs spawned earlier by other fish, losses have not been taken into account in this paper. Consideration will henceforth be limited to such losses.

There was nothing to suggest that any loss of eggs occurred through superimposition in spawning-beds of salmon in the Broken River system or of brown trout in Slovens Creek. In each case there was no crowding of redds into small areas. Redds did not overlap. No samples of eggs were taken from any one redd which, judged by size, colour, and degree of development, were the product of more than one fish. There is evidence that losses were caused in redds of brown trout by superimposition in a number of the streams at Inchbonnie and in the Avon River. While there is no evidence to show that losses were caused in this manner in the Selwyn River and in the Main Drain, the massing of redds, particularly in the former stream, suggested that such losses probably took place. In no case was the measurement of the loss attempted.

In portions of two streams, where redds had been made in water flowing less swiftly than is usual over redds, evidence of loss through superimposition was obtained. In the Avon River beside Park Terrace there is no good spawning-material, and such spawning-areas as there are are of very limited extent. Further, fish of a small average size have to spawn there in fairly slow water, in material so firmly cemented that it is surprising that fish are able to disturb it at all. The result is that fish make slight depressions and deposit ova at a depth of about $1\frac{1}{2}$ in. below the surface of the surrounding stream-bed, and then heap material from the upstream side over the eggs. Subsequent spawners took advantage of the material already loosened by the earlier spawners. In one redd examined three successive pairs of fish had spawned in the one spot. The two later females, in again preparing the same ground for ova-reception, had each displaced earlier ova. The first two lots of ova had been moved when they were in a sensitive state. The dead ova were found seeded through and lying on the surface of the material covering the last batch of eggs. There were recovered of the first batch three specimens, two being dead and one alive ; of the second batch, seventy specimens, of which twenty-two were alive ; and of the third lot 259, all of which, excepting infertile ones, were alive. Other dead ova from the two earlier deposits had doubtless drifted away. In Pigeon Creek, at Inchbonnie, two redds were observed in which dead ova were seeded through the material comprising the redds. In each case a larger sample of good ova produced at a later date by another fish was present in the redd. Each redd was in very slowly flowing water.

Where there is an unusually slow current passing over a redd in which superimposition takes place disturbed ova are not all carried away. Generally, however, there is a sufficiently rapid flow passing over redds to carry away ova which are disturbed by the activities of a later fish. It is in such cases that it is difficult to ascertain whether or not superimposition losses are taking place. The fact that redds overlap one another is not necessarily evidence that losses have been caused during their formation. From the description already given of the size of egg-pockets in relation to the total size of redds it will be plain that it is possible for a considerable

portion of a redd to be disturbed without the egg-pockets being touched. In the Main Drain seven samples of ova were obtained from what appeared to be four redds. In one of these, when the redd had been partially dug, it was noticed that ova of two different fish were being taken from an area of about 2½ ft. by 2½ ft. The degree of cementation of the undisturbed bottom made it possible to distinguish and remove the material loosened by the fish. When this was done two distinct egg-pockets were revealed, separated by a dividing wall of about 4 in. through. Each pocket yielded ova healthy, but quite distinct in colour, and having a development stage difference of 10 per cent.

Generally, in the tributaries of Lakes Brunner and Poerua at Inchbonnie spawning-areas were very congested. As has been stated, the spawning-season lasts for some months in these streams. In 1934, when it was well advanced, twelve trout were killed, some in the daytime and some at night, in the immediate vicinity of spawning-redds. All these fish were ripe. Nine were males and three were females. Eight contained, in the stomachs, numbers of eggs ranging from ten to fifty-three specimens. While a number of the eggs were too digested to enable embryos to be distinguished in them, some of the eggs recovered from seven of the fish had been some weeks old when taken. These fish included two partially spent females, which had been actively engaged in redd-making when captured. The beds of the streams had not been disturbed by floods. There is no doubt that these eggs were taken as they were dislodged from earlier redds by later spawners. An area of 12 ft. by 3½ ft. in Harrys Creek, on which three of these fish were captured, was examined later. From it 6,634 specimens of ova and alevins were recovered. Differences in size, colour, and development suggested that these were the product of at least eleven different females. Dead, disturbed eggs from one redd only were found under surface stones in this area. They were at a point where there was much less current than elsewhere. Yet one fish killed there had eggs of three different females in its stomach. The probability is that heavy losses occurred through superimposition in a number of these redds and that the disturbed eggs were carried away by the current to be eaten by fish or deposited downstream.

Among a number of brown trout handled off redds in Lake Marymere was one which disgorged eggs. Percival (*loc. cit.*) records similar occurrences at Lake Sheppard. It was not clear whether the ova from the trout in Lake Marymere had been disturbed by superimposition or were ova which had not been properly lodged in redds. These eggs were partially digested. Embryos could not be distinguished in them. Mention has been made of the recovery of salmon eggs from the stomachs of trout in Broken River, where no question of superimposition arose. The recovery of eggs in fish guts can only be accepted as satisfactory evidence of superimposition when the ova are taken under circumstances which preclude the possibility of flood-time disturbance, and where development has commenced in such eggs.

E. OTHER POSSIBILITIES OF LOSS.

Indications that ova are killed by being crushed were entirely lacking. The normal occurrence in samples of a fair proportion of live ova, which showed by their distortion and by the different colour of their flattened sides that they had been subjected to pressure for some time, leads to the belief that eggs are not normally killed in this manner. An extreme instance was noted of a live eyed egg which had a maximum thickness of 0·245 in. and a minimum of 0·09 in.

In normal redds, losses of alevins are very light. Of all alevins examined only one was suffering from yolk-sac dropsy. No cases of spinal disorders were found. It is necessary to consider whether or not alevins are killed and eaten by predators in redds. It will be obvious that if this happened dead alevins might not be recovered by usual sampling methods. It has been shown that alevins spend the greater part of their life in the redds in a region practically free of other animal life. By the time alevins have worked up to the immediate surface material, which contains forms of life possibly harmful to them and others probably useful for food purposes, they are no longer the puny larvæ they were at the time of hatching. Yolk-sac absorption is well advanced and the alevins are sufficiently developed to take external food. No evidence was obtained of losses taking place at this time through attack by predators. It seems unlikely that they do occur before the alevins come into open water, where larger free-swimming animals live. Larvæ of the dobson or alder-fly (*Archichauliodes diversus*) and of a stone-fly (*Stenoperla prasina*) were found in the surface material of older redds in most streams. Hudson(13) describes both as feeding chiefly on mayfly-larvæ. These were the only predaceous organisms comparable in size with alevins which were found fairly generally in redds. They were more common in Slovens Creek than elsewhere. Samples of material from the bed of this stream, near trout-redds, showed a total population of from 321 to 540 animals per square foot. Of these, dobson-flies and stoneflies comprised 2 per cent. Half of these were juveniles of smaller size than alevins. The relatively short time during which alevins and predators occupy the same environment, the abundance of other forms of food, and the relatively small numbers of predators indicate that if any loss occurs it must be of small extent. Analyses made by Percival (*loc. cit.*) of fauna in stream-beds in various parts of New Zealand show that generally predators are no more common elsewhere than in the bed of Slovens Creek.

Fresh-water crayfish (*Paranephrops*) were common in the streams at Inchbonnie in summer, but less so in winter. None was found in the material in the surface of redds. Three small eels (*Anguilla dieffenbachii*) were found a little below the surface of spawning-redds: one was in the redd of a brown trout in the Main Drain and two were in redds of salmon in Winding Creek. Their small size, 5 in. to $6\frac{1}{4}$ in., and their relative paucity suggest that their depredations, if any, must be extremely limited. No egg or alevin remains were present in the gut contents of these three specimens.

SECTION VII. -PRACTICAL CONSIDERATIONS.

This paper is essentially a preliminary study. It is concerned with methods of determining the extent of losses in natural redds, the application of these methods to different types of environment, the ascertainment of the causes of the losses found, and the recording of such incidental observations as seem to be of value. No recommendations of immediate practical importance in regard to conservation of stocks of fish follow from the observations made. A substratum of necessary knowledge has been built up. The application of this knowledge to practical problems is a second and distinct phase of the work.

In the main it is the policy of authorities controlling inland fisheries in New Zealand to trap wild fish, where they can be obtained conveniently and in sufficient numbers. The ova are obtained, fertilized, and hatched under artificial conditions. The resultant fry are liberated, generally about the time all yolk is absorbed. They are liberated in waters where it is considered that an increase in the existing stock is most required. The function of the trout hatcheries has for many years past been very largely for maintenance rather than acclimatization. The data presented in this report provide no ground either for recommending modifications of existing policy or for approving it.

It is clear that knowledge of practical value to fisheries authorities should result from an extension of this work. If authorities are to use their resources to the best advantage it is essential that they should know, *inter alia*, what effect the collection of ova from fish in a stream has upon the stock of that stream, which waters ova could be collected from and the proportion which could be collected without reducing the natural hatch, how many fry must be liberated in any stream to achieve any particular result, and whether the results desired could be achieved in other ways.

It is obvious that only a very small proportion of the eggs produced by Salmonidæ can develop into mature fish. The work of White(21) on the American brook trout showed that a tremendous mortality occurred in the first few months following the absorption of the yolk-sac when young fish were liberated from artificial hatcheries into controlled areas of natural streams. It is possible that the present system of fish-hatchery operations in New Zealand safeguards the young over a period through which they are much less in need of protection than in an equal period of time immediately following their liberation. The truth of this matter needs to be ascertained.

SECTION VIII.—CONCLUSIONS.

Data presented justify the drawing of the following conclusions in regard o areas examined :—

(1) The efficiency of fertilization of the eggs of quinnat salmon and of rown and rainbow trout, lodged in natural redds in streams, is remarkably igh. Material from redds of brown trout showed an efficiency of fertilization n excess of 99 per cent.

(2) The incidence of subsequent loss, where heavy loss occurs, is much reater in the pre-eyed than in the eyed ova or in the alevin stage.

(3) Heavy losses of fertilized ova are the outcome of adverse environ- nental conditions and not of inherent weakness.

(4) The extent of losses of fertilized ova in undisturbed redds depends rimarily on the amount of very fine material in the redds during the evelopment of ova before eyeing. It is possible that high water-temperature s a contributing cause of loss.

(5) *Saprolegnia* infection of dead pre-eyed eggs is responsible for losses ova at later stages.

(6) Losses, of unmeasured extent, of the ova of brown trout occur through e superimposition of redds where suitable spawning-areas are of sufficient size for the number of fish which occupy them.

(7) All floods tend to be harmful in that they increase the deposition fine material in redds.

(8) Floods rarely effect the substantial modification of the contours of dds. When they do so they may cause losses considerable enough to count for the partial failure of a year class.

(9) Under favourable conditions natural reproduction is a highly ficient process.

(10) The fact that favourable conditions were found to exist not ncommonly in streams in a belt of country embracing a great variety of onditions suggests that the efficiency of natural spawning of Salmonidæ n New Zealand may be generally higher than was heretofore supposed.

SUMMARY.

(1) This paper is a record of a preliminary investigation of the extent and causes of losses which occur in New Zealand in the spawning-redds of three species of Salmonidæ—*O. tschawytscha*, *S. trutta*, and *S. irideus*.

(2) Data have been collected concerning, *inter alia*, the following matters: —

(*a*) The spawning-habits of the three species.
(*b*) The selection of spawning-areas.
(*c*) The efficiency of extrusion of ova.
(*d*) The efficiency of deposition of ova in redds.
(*e*) The efficiency of fertilization of ova.
(*f*) The nature of redds.
(*g*) The distribution of ova in redds.
(*h*) The causes of losses in redds.
(*i*) The extent of losses in redds.
(*j*) The relative efficiency of different environments.

(3) Methods, regarded as indicative rather than conclusive, have been found for determining whether or not a loss of earlier deposited ova results when later spawners superimpose their redds on those made by earlier spawners. The extent of this loss, where it occurs, has not been measured.

(4) Where eggs or alevins are not disturbed in this manner the method of determining the extent of losses is as follows :—

(*a*) It is ascertained whether or not ova or alevins are removed from the redds by other agencies.

(*b*) Samples of ova and alevins at successive stages of development are recovered from redds, and the extent of the loss shown by each sample is determined.

(*c*) Where observations preclude the possibility of dead ova having decomposed to an irrecoverable state an estimate is made of a the loss up to hatching.

(*d*) Present material is insufficient for the estimation of the percentage loss of alevins between the times of hatching and emergence from the redds. Losses at successive stages of development are shown, and the times required for the decomposition of dead specimens to an irrecoverable stage are indicated.

(5) Observations were made on fifteen streams, from fourteen of which material was collected. These streams are in the South Island of New Zealand in a belt of country extending from tidal water on the Pacific Coast of Canterbury to within eighteen miles of the Tasman Coast in Westland. This belt of country embraces a great variety of environments.

(6) Observations were made on 104 redds of quinnat salmon in three streams. Samples totalling 16,252 ova and 4,146 alevins were obtained from forty-one of these redds.

In Winding Creek a hatch of over 97 per cent. of ova lodged in redds sampled was indicated in 1933. Apart from flood losses, a very low subsequent mortality in the redds was indicated.

In Broken River in that year 76 per cent. of the redds were adversely affected by abnormal weather conditions. The infrequence of the occurrence of such conditions there and in Winding Creek is shown.

(7) Observations were made on spawning-areas of brown trout in fourteen streams. Material was collected from thirteen of these. Redds examined in these thirteen streams numbered 143. The samples taken from them totalled 49,804 specimens of ova and alevins.

In Black Creek, where losses (of unmeasured extent) occur through the disturbance of earlier redds by later spawners, a hatch in undisturbed redds or portions of redds of over 95 per cent. of ova lodged was indicated. A very low post-hatching mortality in the redds was indicated.

In the Selwyn River, where it is not know whether or not later spawners disturb the contents of early redds, in undisturbed redds or portions of redds a loss of less than 3 per cent. before hatching was indicated. A very low post-hatching mortality was indicated.

In Slovens Creek redds were not disturbed by subsequent spawners. A loss before hatching of approximately 25 per cent. of the eggs lodged was indicated without taking into account dead eggs which were no longer recoverable.

Material obtained from redds of brown trout in ten other streams has been used for a study of reactions to different environments.

(8) Samples of ova totalling 3,692 specimens were obtained from four redds of rainbow trout in one stream. The losses shown by these samples are not inconsistent with results obtained in the case of redds of brown trout under similar circumstances.

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APPENDICES.

APPENDIX A.—SALMON-SPAWNING AREAS.

Avoca, 30th November, 1933.

DEAR MR. HOBBS,—

I have fished in N.Z. for 32 years, and for the last 13 years I have lived at Avoca. The floods this winter in Broken River were altogether exceptional. I have never known severe floods to occur in winter in this stream before. The annual spring floods generally start in early October, but sometimes in September.

It is a good 4 years since surface water ran from the lake into Winding Creek. On only one other occasion than this last winter have I seen Winding Creek turbid and in heavy flood—this would be 8 or 9 years ago. Nor' west weather is the only weather to cause floods in these streams.

Slovens Creek too, is a nor' west flooding stream. Nor' west is a very rare thing in the winter and the floods this winter in Slovens Creek were exceptions.

I first saw quinnat in Broken River two years after I came to Avoca in very small numbers. Despite fluctuations, since then, there has been a marked increase and there appears still to be a tendency to increase. This last winter I saw numerous pairs of fish spawning in the Waimakariri both between Broken River mouth and Staircase and above the gorge near the mouth of the Esk. I don't consider that netting returns for the Waimakariri mouth give any true indication of the size of the runs which enter Broken River each year.

Yours faithfully,
(Sgd.) J. KIDD.

D. F. Hobbs, Christchurch.

Mt. White, Cass. 23–XI–33.

DEAR SIR,—

Replying to yours of 8th inst. *re* quinnat salmon.

The fish spawn in Waimakariri, how far they go up I do not know: but I do know they are above railway bridge at Cora Lynn. They also spawn in Poulter and Esk. I have seen them up Poulter at junction of the Thompson in large numbers.

They are usually up in this locality about first week in May, sometimes earlier, it depends on quantity of water in Waimakariri.

Yours,
(Sgd.) J. G. THOMPSON.

Mr. D. F. Hobbs.

Castle Hill, November 20th, 1933.

DEAR SIR —

Yours to hand of 7th *re* salmon in Broken River.

I have seen several fish up the river and know they go up the Porter as far as the Road Bridge.

The spring is the only time there is any flooding in the Porter or Broken Rivers.

Yours faithfully,
(Sgd.) R. A. BLACKEY.

Springfield, December 21st, 1933.

Mr D F Hobbs

In reply to your letter of 5th December, I am sending you the information you are seeking.

Taking the top end first, Cass, the salmon are to be seen spawning in the Waimakariri along the railway from the Cass Creek entrance up to where the Bruce enters it. That is as far up as I have seen these fish, and only odd fish. Around the Cass Creek and up the same, the fish are more numerous and last year on one day nine fish were working in one hole just above the Cass entrance. All of these observations have been from my engine as I travel up and down each day.

In the Waimakariri at this end, I have been in the habit of doing a fair amount of shooting in the riverbed and have seen a lot of these fish in the season. Out from Springfield, where the Kowai enters the Waimakariri, fish spawn very numerously, I have seen at times as many as 30 fish in some of the holes. I have not seen any up the Kowai itself but about two miles higher is a swamp creek known as Hackets Creek and the fish go up that very freely, and I have seen them right up into the swamp itself.

I am, &c.,
Yours sincerely,
(Sgd.) ALEX. D. DICKIE.

APPENDIX B. OCCURRENCE OF CHORIONS IN SAMPLES.

PUNCTURED chorions constituted over 3 per cent. of the specimens comprising samples of ova from Winding Creek. In some cases the chorions had small punctures. More usually they were split from pole to pole. Some contained a little coagulated yolk. The majority were empty.

There was no possibility of these being shells of eggs which had hatched in previous years. Shells undergo a very marked reduction in thickness immediately before hatching—so great a reduction that it was unusual to recover shells with alevins which had recently hatched.

That these shells were relics after animal-attack was extremely improbable. There was no difference in the percentage of shells recovered from newly finished redds and from older redds. The former were virtually devoid of aquatic animals; the latter contained plenty. In each case there was almost an entire absence of animals as deep down as the ova-stratum.

The finding of shells in redds only a few days old indicated the improbability of shells resulting from decomposition of the egg contents.

The experimental planting and subsequent recovery after a considerable time of batches of both fertile and infertile ova showed that shells occurred equally in either case.

The recovery, with samples of eyed eggs, of shells and also occasional prematurely hatched larvæ with crushed yolks suggested that eggs might have been crushed during sampling. A batch of trout-eggs, which had been dead for thirty days but which had not been attacked by *Saprolegnia*, were buried under the same conditions as exist in normal trout-redds. These eggs were dug out again immediately, and of them 6·66 per cent. were recovered as shells. The only satisfactory explanation was that these had been crushed when being dug out. A further batch, this time of live eggs, were buried and recovered under as nearly as possible identical conditions. This time 4·87 per cent. were recovered as shells. Thus clean shells, not infected with *Saprolegnia*, are approximately twice as likely to result from the recovery of uninfected dead ova as from the recovery of live eggs. No notice need be taken here of dead ova infected with *Saprolegnia*. Infected eggs are distinguishable, whether or not they are intact when recovered, and they are dealt with separately. Had transport facilities been available a pick-axe and a crowbar would have been carried to assist in opening up some of the salmon-redds. The shovel had frequently to be used as a lever to loosen large stones, and generally the violence necessary was such that the crushing of eggs was to be expected. It is considered that the explanation offered for the occurrence of shells in samples is the only acceptable one.

Non-fungussed dead ova are about twice as likely to be recovered as shells, as are live ova. The shells of fungussed dead ova are clearly distinguishable and have been added to the ordinary fungussed dead. Fungussed ova need not, therefore, be taken into account in calculating this correction. From redds of salmon in Winding Creek there were recovered, altogether, 13,424 ova and 421 non-fungussed shells. The ova included 300 dead, of which 52 were fungussed. Excluding fungussed ova, there were 13,124 live and 248 dead ova, and 421 shells. From equal numbers of live ova and non-fungussed dead ova, shells will result approximately in the proportion of 1 to 2 respectively.

The following calculation will give a result approximate enough to show whether any serious error will occur if shells are ignored altogether:

Proportion of shells belonging to dead ova $\frac{248}{13,124} \times \frac{2}{1} = \frac{124}{3,281}$

Number of shells belonging to dead ova $\frac{124}{3,305} \times \frac{421}{1} = 15.$

Total live ova = 13,124 + 406 = 13,530,

and total dead ova = 248 + 15 + 52 (fungussed) = 315.

When shells were ignored dead ova constituted 2·28 per cent. of the live, and a loss of 2·74 per cent. up to hatching was shown. If shells are taken into account, dead will constitute approximately 2·32 per cent. of the live, and the loss to hatching would be about 2·78 per cent. It is clear that shells need not be taken into account in dealing with material from Winding Creek.

Shells constituted 3·04 per cent. of prehatching specimens recovered from Winding Creek. They constituted only 3·49 per cent. of pre eyed and eyed specimens recovered from redds of brown trout in Slovens Creek. In this stream the loss before hatching was very heavy. Under equal circumstances a greater proportion of shells should result where losses are heavier. Less violence had, however, to be employed in digging out the comparatively shallow redds of brown trout in Slovens Creek and elsewhere. Throughout this paper a practice has been followed of excluding shells from the totals shown of samples recovered in the pre-eyed and eyed stages. Where, however, shells and dead ova have been recovered with alevin samples, and it has been necessary to use such samples for the estimation of pre-hatching losses, shells have been apportioned between the non-fungussed pre-eyed and eyed ova and have been included in the totals of samples.

APPENDIX C.—AGE OF OVA AND ALEVINS OF BROWN TROUT.

For age-determination purposes an endeavour was made in 1932 to obtain ova and alevins from an experimental hatchery at Avoca. After sixteen days had elapsed the ova were removed to a floating hatchery-box in Slovens Creek as temperatures over that period had averaged 0·5° C. In Slovens Creek these ova were subjected to a range of temperature varying between 4·8° and 11°. During alevinage temperature ranged from 8·5° to 14°. Two series of samples of ova of known age were obtained—one in 1932 and one in 1933—from the North Canterbury Acclimatization Society's hatchery at Greenpark. It is only known that temperature over the whole incubation period in either year had a mean of 9·2° C. with a variation of 2° either way. Of necessity, a mean temperature of 9·2° has been accepted for the portion of the incubation period covered by each sample.

It is clear that the durations of the incubation and alevinage periods are less at high temperatures than at low temperatures. Green [cited by Day (*loc. cit.*)] gives a rule for the ova of *Salvelinus fontinalis* that, in water of 50° F. ova will hatch in fifty days and that, for every degree Fahrenheit warmer or colder, the incubation-period is reduced or increased respectively by five days. This rule is generally accepted by hatchery curators in New Zealand as applicable to the ova of brown trout. At temperatures ranging from 7° to 12° C. it has been found a reliable guide by the present writer. Gray(10) gives incubation-periods for ova of brown trout at different temperatures. This material was supplied to Gray by hatchery-owners in England. Gray's data are reproduced in the first two columns of Table 21. The duration of incubation at like temperatures, as calculated to the nearest day from Green's rule, is shown in the third column.

Table 21

Temperature.	Incubation-period, in Days (per Gray).	Incubation-period, in Days (per Green's Rule).	Difference, in Days.
2·8	165	115	−50
3·6	135	108	−27
3·9	121	105	−16
4·5	109	99	−10
5·0	103	95	− 8
5·7	96	89	− 7
6·3	89	83	− 6
6·6	81	81	0
7·3	73	74	+ 1
8·0	65	68	+ 3
9·0	56	59	+ 3
10·0	47	50	+ 3
11·1	38	40	+ 2
12·2	32	31	− 1

The writer has noticed that with ova from the same fish fertilized at the same moment hatching may extend over seven days. Gray does not state whether the figures supplied him are up to the beginning, peak, or end of hatching. It is possible that there was a lack of uniformity of method on the part of the different individuals who supplied the material. While there is a marked and progressive disparity between observed and calculated incubation-periods at temperatures of less than 6·6°, the disparity at temperatures of between 6·6° and 12·2° is small. It is interesting to note that the range over which Green's rule applies is coincident with that in which Wood (*loc. cit.*) found the maximum efficiency of development to take place.

As ova in the Avoca hatchery had been incubated for a considerable period at temperatures of less than 2·8° it was found necessary to rely solely on the Greenpark material. This latter material was incubated at a temperature which, although it varied, varied within the limits in which a substantial agreement is manifested in Table 21.

Data as to the duration of alevinage at different temperatures, given in manuals on fish-hatchery practice, are not acceptable in that the terminal point of development is not defined. Generally in hatcheries in New Zealand alevins are termed "fry" as soon as external feeding is commenced. Feeding is commenced before all the yolk is absorbed. Gray(9) found that at 10° C. 100 days elapsed from fertilization until absorption of all yolk ceased. He does not note the time of hatching of this particular material. It is assumed that the figure of forty-seven days for incubation at 10° C., given elsewhere, Gray(10), is applicable to this material. Thus Gray found that at 10° alevinage extended for fifty-three days.

Wood obtained a batch of ova which, after incubation for fifty-six days from fertilization, had reached hatching-point. This figure would result from a temperature of 9° C. during incubation. Wood reared alevins obtained from these ova at temperatures of 3°, 7°, and 12° C. He found that 108, 58, and 27 days respectively elapsed after hatching before yolk ceased to be visible on the ventral surface. This was a point of development in the vicinity of that attained by Gray's material at the eighty-fifth day. It is possible that there was a lack of uniformity on Wood's part in fixing the terminal point of development. His data show that one sample—that at 3°—had passed the point up to which larval weight increases; the other two samples had not. The figures he gives for yolk-sac absorption are accepted by the present writer as approximate times taken to reach a point of development approximately similar to that reached by Gray's material on the eighty-fifth day from fertilization at 10°. Gray's material, which hatched at the forty-seventh day of the 100 days required for total development, had at the eighty-fifth day passed through $\frac{38}{53}$ of the total alevin period. On this basis, in the case of Wood's material, the total alevinage periods would, at 3°, 7°, and 12°, have extended for approximately 151, 81, and 38 days respectively.

The present writer hatched ova and reared alevins in hatchery floats in Slovens Creek at Avoca, and in School, Pigeon, and Waterfall Creeks at Inchbonnie. With the exception of the material from Slovens Creek, which had previously been incubated for sixteen days at a temperature of 0·5° C., the material in the different boxes was subjected only to temperatures which occurred in these streams to which naturally spawned ova and resulting alevins are subjected. The ranges of temperatures, however, to which the contents of the hatchery-boxes were subjected were not those to which the bulk of naturally spawned ova were subjected. The data from different sources are given in Table 22, in which are also given the incubation-periods operating at the same mean temperatures as those to which alevins were subjected. Temperatures given are in degrees Centigrade.

Table 22.

Source of Material.	Temperature of Incubation.	Range of Temperature of Alevinage.	Mean Temperature of Alevinage.	Duration of Alevinage (Days).	Incubation Period at like Temperature.	Difference, in Days.
Wood	9·0	Nil	3·0	151	158	− 7
Wood	9·0	Nil	7·0	81	77	+ 4
Waterfall Creek ..	1·25 to 8·5	3·5 to 10·5	7·8	52	67	−15
Gray	10·0	Nil	10·0	53	47	+ 6
School Creek ..	8·0 to 11·0	8·0 to 12·0	10·2	42	44	− 2
Slovens Creek ..	0·5 to 11·0	8·5 to 14·0	11·0	43	37	+ 6
Wood	9·0	Nil	12·0	38	33	+ 5
Pigeon Creek ..	10·0 to 11·5	12·5 to 17·5	14·8	18	..	..

It will be noted that in the case of the Waterfall Creek material temperature during alevinage ranged from a point below that at which the duration of incubation is inversely proportional to temperature. It has been remarked that at such low temperatures Green's rule has no application, and it follows that the duration of incubation cannot necessarily be calculated from mean temperature. It is probable that this is also the case during alevinage. The differences between the duration of alevinage and incubation, at like temperatures, shown by the rest of the material are no more than might be expected in view of the unsatisfactory aspects of the material. If the Waterfall Creek material is excluded, the rest of the material indicates that, over a wide range of temperatures, the durations of incubation and alevinage are approximately the same.

While this material cannot be regarded as wholly satisfactory for ascertaining the duration of incubation and alevinage at different temperatures it is sufficient to enable rules to be laid down which will enable these periods to be defined with a reasonably small margin of error. It is accepted that, at temperatures of between 6·6° and 12·2° C., Green's rule is equally applicable for determining the duration of both incubation and alevinage—that is to say, at 50° F. each period will occupy fifty days, and the duration of each period will become longer or shorter by five days for each degree Fahrenheit by which temperature is reduced or increased. At temperatures of less than 6·6° C. Gray's data, as reproduced in Table 21, are accepted as applicable to both the incubation and alevinage periods. Although in Table 22 the duration of alevinage at 14·8° C. is shown, material was not collected from natural redds in which the mean temperature of incubation exceeded 12·2°.

A temperature of 10° C. is the most convenient at which to trace the development of embryos and larvæ. At such a temperature total development occupies 100 days and hatching occurs at the fiftieth day. It is therefore possible to consider development per diem as development per centum at this one temperature. Thus hatching occurs when ova are 50 per cent. developed.

The samples of ova of known age obtained from the Greenpark Hatchery developed at a mean temperature of 9·2°. The age of each sample has, by the application of Green's rule, been reduced to the age each would have been if incubated at 10° C. In like manner the age of each alevin sample from the control-box at Avoca has been converted to age as at 10° C., and ages in days at this temperature have been considered as percentages of development. As with salmon ova, the ratio of embryo length to egg-diameter at each age was determined. With alevins, the percentage by weight of embryo to larva was determined. The resultant data for the growth of embryos and alevins as at 10° C. are given in Figs. 5 and 6 respectively. The growth-curve for alevins in Fig. 6 is based on determinations given by Gray(9). The material used by Gray developed at a uniform temperature of 10° C. The development of the Avoca material was not inconsistent with that of Gray's material.

It is necessary to consider the question of whether or not hatching always occurs at a uniform point of development. Have the terminal points of incubation and the point of commencement of alevinage been properly fixed in Figs. 5 and 6 respectively? Gray(10) completed the incubation of different batches of ova, which had first been incubated for thirty-five or thirty-eight days at 10° C., at temperatures of 5°, 9°, 10°, 15°, and 17° C. Respectively, the percentages by weight of embryos to larvæ at hatching were 31 per cent., 24 per cent., 23 per cent., 18 per cent., and 17 per cent. In other words, yolk amounted to 69 per cent., 76 per cent., 77 per cent., 82 per cent., and 83 per cent. respectively by weight of alevin and yolk. Gray thus shows that eggs hatch precociously early at high temperature. Temperatures of 15° or 17° C. were not encountered during the incubation of material from redds discussed in this paper. The mean temperature, to which the average redd from any stream dealt with was subjected, fell between 5° and 11° C. The contents of no individual redd were incubated at a higher mean temperature than 11°. In a very few cases individual redds were subjected during incubation to mean temperatures of below 5°. It is not clear whether the results of incubation at mean temperatures, in streams where temperature fluctuated from day to day, are strictly comparable with the results obtained by Gray when incubation proceeded for a long period at one temperature and then at another temperature. Gray's determination of 23 per cent. as the percentage weight of embryo at hatching was made, however, after incubation at a uniform temperature of 10° C. In School Creek at Inchbonnie, where ova were incubated at temperatures ranging from 8° to 10° with a mean of 9·4°, the percentage weight of embryo was 25 per cent. In Waterfall Creek a sample of ova, incubated at a mean temperature of 4·3°, with a range of from 1·25° to 8·5°, hatched when the embryos constituted 29 per cent. by weight of the larvæ. This was an exceptionally low mean-temperature for incubation—lower than that in any individual redd in Slovens Creek and lower than that for the average

redd in any stream dealt with in this paper. In the Selwyn River, where a comprehensive collection was made of samples from redds, a variation of from 8·5° to 11° was noted, with a mean of 9·9°. With the exception of Jims Creek at Inchbonnie, in which only five redds were sampled, the mean temperature of incubation of the contents of the average redd in any stream was higher in the Selwyn than elsewhere. A variation in percentage weight of embryos of from 23 per cent. to 29 per cent. should cover practically all cases dealt with in this paper. For convenience, a standard of 26 per cent. has been accepted for all, as the point of commencement of alevinage. Further, it has been accepted that at the terminal point of the incubation-period the length of embryos is 2·6 times the diameter of the eggs. It so happened that no samples were taken which conflicted with the practice adopted—that is to say, neither samples of alevins in which weight of embryo amounted to less than 26 per cent., nor samples of ova in which the accepted ratio was exceeded, were taken. The error resulting from the adoption of these standards will be very small. For example, at 10° C. it takes fifty days from hatching until total absorption of yolk. The yolk at hatching-point represents 74 per cent. of the larva. Thus yolk is reduced by approximately 1·5 per cent. per day over the fifty-day period. At 10°, therefore, an error of 3 per cent. at the time of hatching is equivalent to an error of about two days. But in practice the alevin loss is calculated on the basis of fifty days and not forty-eight days for complete absorption. Incubation at 10° produced larvæ, 23 per cent. by weight of which is embryo; after incubation at 4·3°, 29 per cent. is embryo. When a standard of 26 per cent. is accepted and the temperature during alevinage is 10°, a loss shown to occur up to the tenth day is really in respect of twelve days after incubation at 10° and in respect of eight days if incubation has proceeded at a mean of 4·3°. Consequently in the former case the computed total loss during alevinage is very slightly reduced, while in the latter case this loss is slightly increased. Compensation occurs, however, because the actual duration of incubation has been increased in the former case and reduced in the latter case—this, because a standard point of termination of incubation has been accepted. The cumulative effect is to leave the total loss for the combined incubation and alevinage periods virtually unchanged and slightly to increase the loss during incubation at the expense of the loss during alevinage after incubation at high temperature, and *vice versa* at low temperatures.

Samples were assigned to the three main categories of pre-eyed ova, eyed ova, or alevins according to the category into which the majority of specimens in a sample fell. The arbitrary determination of whether or not the eyes of embryos are pigmented gives scope for a little error. To this fact is attributed the placing in the pre-eyed category of a sample from Slovens Creek which was 26 per cent. developed, while a sample of like development from Black Creek was classified as eyed. It is to be expected that such border-line cases, difficult of classification, will be found. In the Selwyn River, however, two samples 27 per cent., and one 28 per cent. developed, were collected which were pre-eyed, while eyed ova of less than 29 per cent. developed were not found. It appears that not only do eggs hatch precociously early at high temperatures, but the embryos in them attain a greater size before eyeing. The terminal point of the pre-eyed period as shown by each series of samples has been accepted for that series.

APPENDIX D.—RESPIRATION OF OVA AND ALEVINS.

Wood (*loc. cit.*) has determined the oxygen-requirements of the alevins of brown trout at different temperatures and at different stages of growth at each temperature. His determinations do not apply to the whole of alevinage. They are in respect of a period from hatching on until about the 85-per-cent. development-stage. Thus they cover most of the period of development in the redds. Wood found that the times required for development up to this point at 12°, 7°, and 3° C. to be 27, 58, and 108 days respectively. For convenience of comparison of intensity of respiration, development from hatching to this point is considered here as taking place over a period divisible

into twenty-seven equal units of development. So shown, Wood's data are reproduced in Table 23.

TABLE 23.

Units of Development.	c.c. O_2 per gm. Embryo per Hour at Successive Stages of Development.		
	At 12° C.	At 7° C.	At 3° C.
1	0·61	..	..
2	..	..	0·20
3	0·67	0·315	0·23
4	..	..	0·22
6	0·66	0·315	..
7	0·69	..	..
9	0·64	..	0·22
10	0·66	..	0·22
11	0·64	..	0·22
12	0·66	..	..
14	0·58	..	..
15	..	0·315	..
16	0·61	..	0·22
17	0·54	0·315	..
18	0·54	0·315	0·22
19	..	..	0·21
20	..	0·27	..
21	..	0·24	..
22	0·45	..	..
23	..	0·19	0·16
26	0·43	0·14	..
27	0·40	..	0·13

It will be seen that the oxygen-requirement per hour is at 3° approximately one-third and at 7° approximately one-half what it is at 12° C. In each case a decrease in intensity of respiration over the later portion of development is shown.

APPENDIX E.—EELS AND TROUT OVA.

Greenpark.

DEAR MR. HOBBS,—

Each Winter for the last 12 years I have trapped trout in the Selwyn River to obtain ova for hatchery purposes.

Frequently ripe females have had to be held for 24 hours in pens for more males to arrive. On the only occasion that I left two large eels (of about 15 lb.) in a pen overnight with ripe female brown trout all the 30 odd trout were spent in the morning. This is the only time that I have found ripe female fish penned up away from males to lose their eggs.

In the past three Winters there have been no floods in the Selwyn. The only floods in the last 3 years big enough to cause a flow of surface water from the source to the mouth have occurred in the summer.

The Selwyn River is usually dry from about a mile above the Ellesmere Bridge to a mile below Colgate—a distance of about 20 miles.

(Sgd.) J. DIGBY,
24–3–34.

E. V. PAUL, Government Printer, Wellington—1937.

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